



# Property Risk Consulting Guidelines

A Publication of AXA XL Risk Consulting

PRC.17.1.1

## SEMICONDUCTOR MANUFACTURING

### INTRODUCTION

A semiconductor fabrication plant (fab) can appear to be a noncombustible, low hazard facility. However, the large quantity of combustible liquids, flammable liquids and flammable gases used in the process, and the plastic construction materials in process equipment, ductwork and containers present an appreciable combustible loading.

The potential for large dollar losses in semiconductor facilities is enormous. Most processes are carried out in cleanrooms, which are highly susceptible to contamination from smoke, other products of combustion and chemical releases. Each wafer the cleanroom produces may contain hundreds of chips. Chip value ranges from a few cents to several hundred dollars. Soot particles or acidic gases from a fire can easily ruin exposed chips and contaminate cleanroom equipment.

Chips do not represent the only high values in semiconductor manufacturing facilities. Major pieces of production equipment have values from \$5,000,000 to over \$15,000,000. The value of a process area often exceeds \$10,000/ft<sup>2</sup> (\$105,000/m<sup>2</sup>). Replacement time for equipment can range from 3–18 months.

Cleanroom and contaminated equipment cleanup costs, damaged chip and equipment values, and lost production time often add up to a major loss. The dollar loss caused by a small fire in a well protected semiconductor facility can easily exceed \$5,000,000. Shutdown of critical utilities, even for a short time, can greatly increase the loss amount.

Semiconductor facilities lacking excellent management loss prevention programs and full protection are more likely to suffer multimillion-dollar property losses and much larger business interruption losses. To reduce the chance of such catastrophic losses, all cleanroom hazards must be properly protected, and all critical utilities must be reliably backed up. Cleanrooms must be arranged to restrict damage from a loss to as small an area as possible. The amount of plastics used in process equipment must be kept to a minimum, and hazardous materials must be closely controlled.

Maintaining effective loss prevention and control in semiconductor facilities is a constantly increasing challenge. One reason is that the property value of these facilities has been rapidly rising, as have their sales and profits. Even very minor incidents result in increasingly expensive losses.

Changes to semiconductor processes have also increased the challenge. The main change is the need for cleaner cleanrooms to keep step with new chip technology. (See PRC.17.11.0.) Almost all processes must now be done in Class 1 or cleaner cleanrooms or in equally clean mini-environments. Each semiconductor manufacturer defines its own standards for rooms cleaner than Class 1.

Another factor in loss exposure is change in cleanroom layouts. In some cases, cleanrooms are getting larger and larger, exposing more process equipment (tools) and stock-in-process to the same loss incident. On the other hand, some Class 10 to Class 1000 cleanrooms are being equipped with

cleaner mini-environments that are small cleanrooms within a cleanroom. These environments use sophisticated robotics and “cluster” many tools into one piece of equipment. Such cluster tools can be worth up to \$20,000,000. The exposure to loss is no less than in a large cleanroom.

Many semiconductor processes use similar tools (e.g., wet benches), and many tools use similar equipment (e.g., vacuum pumps). Likewise, many semiconductor processes use the same materials (e.g., acids, alcohols) for that reason; this PRC Guideline discusses process materials and equipment in separate sections.

The remainder of this industry abstract is divided into the following sections:

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The first section outlines the process of making semiconductor chips. The last four sections discuss loss exposures and present AXA XL Risk Consulting recommendations for loss prevention and control.

The following appendices are also provided:

| <u>Appendix</u> | <u>Title</u>                                 |
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| PRC.17.1.1.A    | Semiconductor Glossary                       |
| PRC.17.1.1.B    | Chemicals Used In Chip Fabrication           |
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## SEMICONDUCTOR PROCESSES

Microelectronic chips are manufactured on wafers sliced from large crystals. The crystals are grown from polysilicon or other semiconducting element, a semiconducting compound, or a mixture of these materials.

The three major processes from the semiconductor material to the chips are crystal production, wafer production and chip production. Crystal production is normally done at a separate facility. Wafer and chip production may be at separate or combined facilities. The steps involved in each of the major processes are shown in Figure 1.

The fabricating step shown in Figure 1 represents the process of etching the desired circuit pattern into the chips being manufactured. This complex process is further broken down in Figure 2. The processes in Figures 1 and 2 are further described in the following sections.

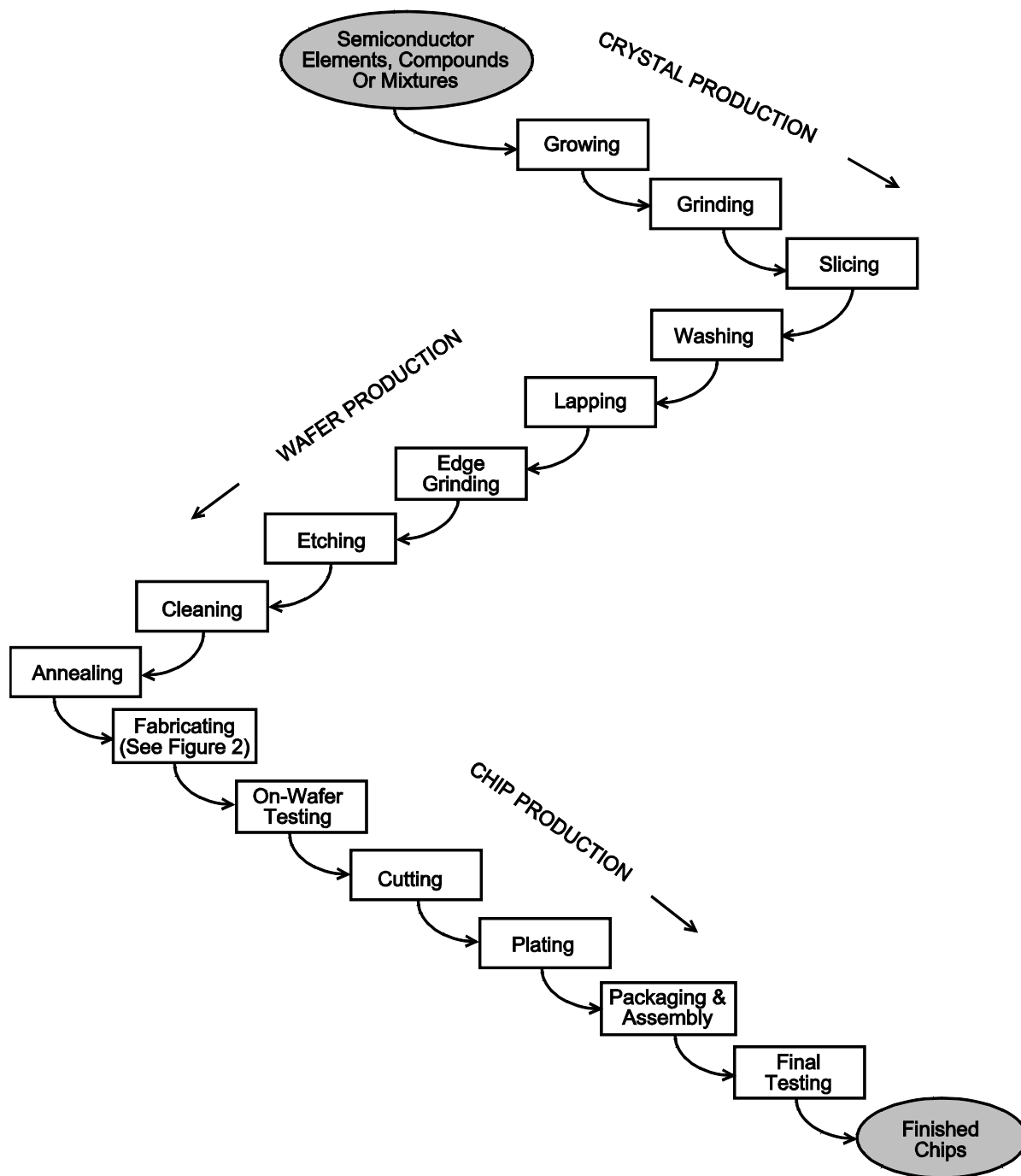
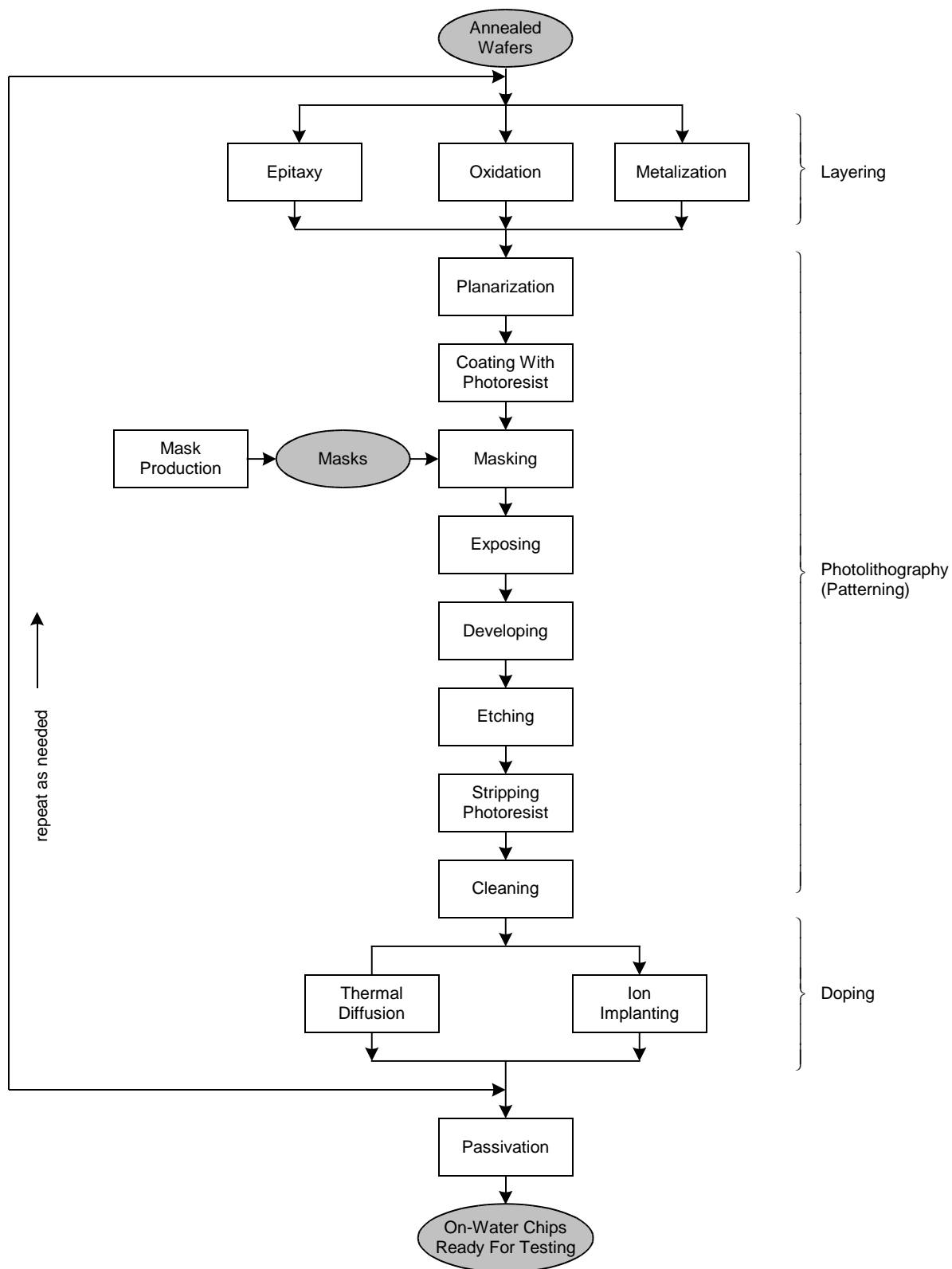


Figure 1. Process Flow Chart For Semiconductor Manufacturing.



**Figure 2.** Process Flow Chart For Chip Fabricating.

## Crystal Production

Semiconductor crystals are made from a variety of materials, the most common being silicon and gallium arsenide. Other materials used to grow crystals include gallium phosphide, gallium arsenide phosphide, germanium, indium phosphide, mercury cadmium telluride, sapphire and some mixtures of these materials.

### Growing

Growing semiconductor crystals is much like dipping candles. The majority of crystals are grown using the Czochralski method, in which an electrically heated crucible filled with semiconductor grade polycrystalline material is maintained at a temperature slightly above its melting point. A seed crystal is dipped into the molten liquid and rotated. Heat flows from the liquid into the seed and causes some of the liquid to crystallize on the seed's surface.

The diameter of finished crystals is typically from 3 in. (76 mm) to 12 in. (300 mm). To create a large uniform crystal, a puller continuously pulls the growing crystal out of the melt. To make the crystal shape uniform, the crucible rotates while the crystal is pulled. Crystals are pulled in lengths up to 12 ft (3.9 m).

Another method of crystal growing is called the "float zone process." This process starts with a rod of silicon attached to a chuck in a vertical heating chamber containing an inert atmosphere chamber. A seed crystal is attached to an opposing shaft. Heat from an RF heating coil wound around the base of the chamber causes a molten zone to form on the rod. The molten material is then fused to the seed crystal and begins crystal formation. Moving the molten zone along the rod purifies the material and establishes a single crystal structure. Often, the crystal is doped during this process by adding diluted concentrations of phosphine or diborane.

### Grinding

Grinding prepares the crystal ingots for slicing into wafers. First, the ends of the ingot are cut off using water-lubricated diamond saws. Next, the ingots are ground to a uniform diameter after which the ends are chamfered to reduce the possibility of shattering. Water-based cutting fluids are used during the cutting and grinding processes.

The direction of the ingot's crystalline structure is determined using x-ray diffraction and is marked by a process called ingot flatting. The ingot is then etched using acids to further delineate the crystalline structure.

### Slicing

Ground crystals are attached to a graphite carrier rod, aligned on the wafer saw, and sliced into wafers. The wafer saw has several diamond-tipped saw blades.

## Wafer Production

### Washing

Wafers are washed with flammable solvents and corrosives, usually in a wet bench beneath a plastic laminar flow hood. The hood supplies air to the bench, then lip exhaust on the bench discharges the air into the fume exhaust system. Washing liquids can present a substantial fire hazard. Wet benches increase the fire hazard if they are made of plastic or have any plastic parts.

### Lapping

After washing, the flat surfaces of the wafer are lapped. The wafers are laid flat in large plates that rotate. Slurry passing between the rotating plates removes uneven silicon on the wafer surfaces. Lapping removes ridges formed when slicing the wafer and makes its surfaces very smooth. It also makes the two wafer surfaces parallel to each other.

## Edge Grinding

The edges of the wafers are smoothed and beveled with edge grinders. This makes handling the wafers easier and reduces chances of damaging the edges. After edge grinding, identification codes are usually put on the wafers with lasers.

## Etching

Wafers are dipped into acid solutions in etching tanks to remove any remaining surface defects and to reduce wafer thickness. Acid etching also polishes the wafer.

## Cleaning

After etching, wafers are cleaned and rinsed in a series of baths. Deionized water is used for the first rinse. The wafers are next cleaned with flammable solvents and corrosives, then rinsed in isopropyl alcohol to aid drying. Cleaning and rinsing is usually done in a wet bench beneath a plastic laminar flow hood. The hood supplies air to the bench, then lip exhaust on the bench discharges the air into the fume exhaust system.

Common cleaning chemicals are acetone, hydrogen peroxide and acids. The flammability and reactivity of these chemicals can present a substantial fire hazard. Wet benches increase the fire hazard if they are made of plastic or have any plastic parts.

## Annealing

Wafers are annealed in furnaces at about 600°C (1100°F). Annealing stabilizes the semiconducting properties of the wafer base material. At this point, the wafers are ready to have chips fabricated on them.

## Chip Production

### Fabricating

Chip fabrication is the most hazardous and expensive operation in the semiconductor process. The combination of ultraclean air, expensive process equipment, extensive use of hazardous materials, and the presence of plastics in the cleanroom creates the potential for catastrophic losses if the cleanroom is not properly protected.

Fabricating chips on wafers involves building up circuit layers, etching patterns into the layers using photolithography, and doping the patterns to achieve the desired electrical characteristics. These key process building blocks can be called layering, patterning and doping. After repeating these three blocks the required number of times, a passivation step completes the chip. Figure 2 shows which process steps these blocks include.

Fabricating different kinds of chips requires following the steps in this figure different numbers of times and in different ways, depending on the circuit technology and complexity. Each cycle through the loop can involve one or more of the steps shown. Most chips require 6-10 cycles; some may require up to 40. Future chips may require even more.

### 1. Layering

Layering adds the materials needed to build a chip. These include semiconducting, nonconducting and conducting materials. Layering of these materials is called epitaxy, oxidation and metallization, respectively. The proper combination and arrangement of these materials achieves the desired circuit design.

In **epitaxy**, a single crystal film of semiconducting material is applied by a rigidly controlled deposition process. For silicon wafers, the film is produced by chemical vapor deposition (CVD) of flammable and pyrophoric gases injected into an epitaxial reactor operating between 900°C (1650°F) and 1300°C (2370°F).

In the **oxidation** process, a nonconducting layer of silicon dioxide is formed to protect the wafer surface from impurities and protect already completed layers from subsequent patterning and doping processes. There are two basic oxidation methods: dry and wet.

Dry oxidation takes place in a furnace. The in-process wafers are cleaned, dried, loaded into a quartz holder called a “boat,” and placed in a quartz diffusion furnace. The furnace is injected with dry oxygen, which oxidizes the wafer’s surface.

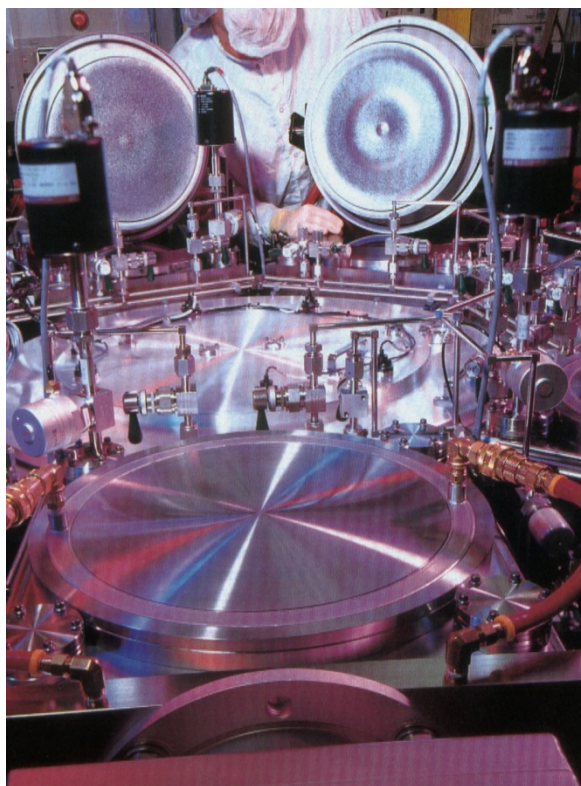
The four wet oxidation processes are pyrophoric, high pressure, flash and bubbler oxidation. These processes use water vapor in combination with oxygen or nitrogen, and equipment similar to that used in dry oxidation.

Most semiconductor fabs have vendors perform the initial epitaxy and oxidation steps on the wafers; and the fabs perform the remaining steps. These steps must take place in cleanrooms.

In **metallization**, conducting material is placed to make the required electrical connections between the electronic devices formed in the layers of the chip. Until recently, this conducting material was almost exclusively aluminum and its alloys, with minor use of nichrome and gold. Copper is now being used in small-geometry circuits because its low electrical resistance and low rate of heat generation allows smaller connections and higher circuit speeds.

Aluminum is applied in either thin film deposition or plating processes. Copper is applied by electroplating.

Thin film deposition of metals is a physical vapor deposition (PVD) process. (See Figure 3.) This process uses high vacuum or partial vacuum evaporation techniques. High vacuum techniques are electron beam, flash, and resistive deposition, while partial vacuum deposition is done by sputtering. Sputterers are often worth over \$3,000,000.



**Figure 3.** Physical Vapor Deposition (PVD) Process. Photo courtesy of Novellus

Thick film metallization is done by a silk-screen process. Since most thick films are not compatible with silicon integrated circuits, this process is usually found in the production of hybrid electronic structures, such as liquid crystal displays (LCDs).

Plating is done by either electroplating or electroless plating. With electroplating, the wafer is the cathode and an electrode made of the plating metal is the anode. Electroless plating uses a simultaneous oxidation and reduction of the plating metal to produce the ions that attach to the wafer.

After metallization, alloying and annealing may be performed. Alloying assures contact between the metal and the wafer substrate. Annealing optimizes and stabilizes the chip's characteristics. Both processes are performed inside separate diffusion furnaces with the alloying process using vaporized aluminum and the annealing process using hydrogen gas.

After each of the layering steps, a chemical mechanical polishing step smoothes the surface of the wafer to achieve better results in photolithography. This step is called **planarization** (see Figure 4).

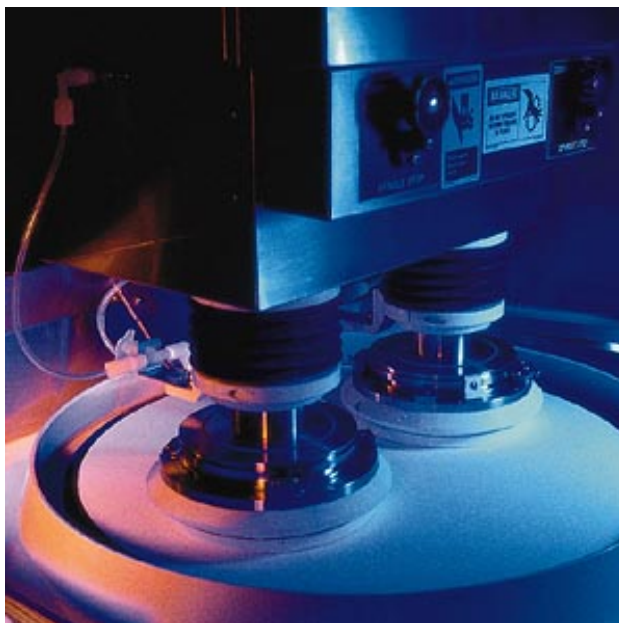


Figure 4. Planarization/Polishing Process.

## 2. Photolithography

Photolithography brings the masks and wafers together to etch the desired circuit onto the chips that will be cut from a wafer. The process is similar to creating a photograph. The mask is the “negative,” the circuit on the mask is the “image” to be copied, and the wafer is the “paper” on which the image is developed. The mask can be either a positive or negative of the circuit image, depending on the process.

The first step in photolithography is **coating with photoresist**. The wafer is first coated with a thin layer of hexamethyl disilazane (HMDS) followed by a photoresist emulsion (light-sensitive chemical). The HMDS helps the photoresist adhere to the wafer. Both materials are applied using a “spinner.” The wafer is then placed in a temperature controlled oven, often with a nitrogen atmosphere, causing the photoresist to cure (soft bake) and any remaining solvents to evaporate.

The next step is **masking**. The mask is a thin, patterned sheet that shields portions of semiconductor material during wafer exposure. Each mask contains the pattern for a single layer of a circuit, so several masks are needed to make a completed circuit.

**Mask production** takes place in cleanrooms. A computer aided design (CAD) system is used to design and lay out the masks. The CAD system transmits the finished design to either a wafer-stepper or electron beam (E-Beam) system.

The wafer-stepper uses a light beam to transfer an image of the mask to a master plate used to make the working masks. The electron beam lithography system, called an “E-beam” system, is similar to a wafer-stepper, but uses an electron beam. The advantages of the E-beam include speed of mask production, defect control and superior image quality. A complete E-beam machine can cost well over \$10,000,000.



Masks are typically glass-covered with photoresist or high-resolution emulsions. Mask producing operations usually have combustible loading in the form of plastic hoods and containers, flammable photoresists and high-resolution emulsions.

The next step is **exposing**. Through the mask, the wafer is exposed to ultraviolet light, which changes the solubility of the photoresist in the unmasked areas. The solubility difference allows the photoresist on either exposed or unexposed areas to be washed away.

More complex E-beam machines and direct-writing systems expose the wafer without using masks. In this process, the wafer is coated with an electron-sensitive photoresist, placed in the E-Beam unit, and exposed to the electron beams. The beams etch a layer of the circuit directly onto the wafer.

In the **developing** step, a solvent-based developer is applied to the surface of the wafer. Methods for applying developer include immersion, spraying and atomization. This step prepares the photoresist to be polymerized by heat. Excess developer is rinsed off with a solvent-based rinse. The wafer is then hard baked in a temperature-controlled oven so the photoresist can fully polymerize on the wafer surface.

After hard baking, the unpolymerized photoresist and the layer just beneath it are removed. This **pattern etching** is done by either chemical stripping or plasma etching. Chemical stripping uses acids and other chemicals to strip away the unpolymerized photoresist and is done at wet benches. Wet benches using acids are often made of polypropylene plastic, as are the tanks that hold the acids. (See PRC.17.11.0 and PRC.17.11.1.)

Plasma etching is done in machines called plasma ashers. These machines use an RF power source with oxygen inside a vacuum reactor chamber. The power source ionizes the oxygen, which reacts with the photoresist to form products that can be removed by the vacuum system.

After unpolymerized photoresist is removed, oxide layers, metals and polysilicon (or other semiconducting materials) are removed by one or more of the following methods:

- Chemical stripping
- Plasma etching
- Microwave downstream etching
- Physical etching
- Sputter etching
- Ion beam etching and milling
- Reactive ion etching.

After the pattern has been etched, the next step is **stripping the remaining photoresist**. This is done with either wet chemical stripping or plasma etching.

The last step in the photolithography process is **cleaning**. After stripping, wafers are cleaned and rinsed in a series of baths. Deionized water is used for the first rinse. The wafers are next cleaned with flammable solvents and corrosives, then rinsed in isopropyl alcohol to aid drying. Cleaning and rinsing is usually done in a wet bench beneath a plastic laminar flow hood. The hood supplies air to the bench, then lip exhaust on the bench discharges the air into the fume exhaust system.

Common cleaning chemicals are acetone, hydrogen peroxide and acids. The flammability and reactivity of these chemicals can present a substantial fire hazard. Wet benches increase the fire hazard if they have any plastic parts.

### 3. Doping

When the remaining photoresist has been removed, doping fuses desired impurities into the semiconducting material exposed on the wafer by the previous step. Dopants allow a controlled flow of electrons through the chip by providing a switched electrical path. Dopant materials can be solids, liquids or gases and can be flammable or combustible. Dopants are introduced into the chips using either a diffusion furnace or an ion implanter.

In the **diffusion** process, the wafers are stacked in a boat and placed in a diffusion furnace. Temperature control is vital, as dopant diffusion rates are temperature-dependent. Dopants are fed to the furnace in vapor form and are absorbed on the exposed areas of the wafer substrate.

For maximum process control, diffusion operations are done in two separate furnaces. The first furnace operates at a set temperature that allows a good supply of dopant material to be deposited on the wafer surface. The second furnace runs at a higher temperature to diffuse the dopant to the desired depth.

**Ion implanting** is a newer dopant injection method. With this method, the dopants can be implanted at room temperature instead of elevated temperatures. Dopant is passed through a high voltage electric field, which ionizes the atoms and accelerates them to a high energy level. The ions are aimed at the wafer and become implanted in areas not protected by photoresist or by the oxide layer.

The depth of the implant depends on the mass of the ion and its energy. After implantation, the wafer is annealed at high temperature to repair any wafer damage from bombardment by dopant ions. Ion implanters cost over \$2,000,000 per unit and can take up to 6 months to replace.

#### 4. Passivation

After the wafers have completed all the layering, patterning and doping cycles for the chip being made, the chips' circuitry is complete. Since the chips' final exposed surface is still delicate, it must be given a final coating to protect the chip from electrical and chemical environment hazards. Passivation is a CVD type process that coats the wafer surface with an oxide layer.

#### On-Wafer Testing

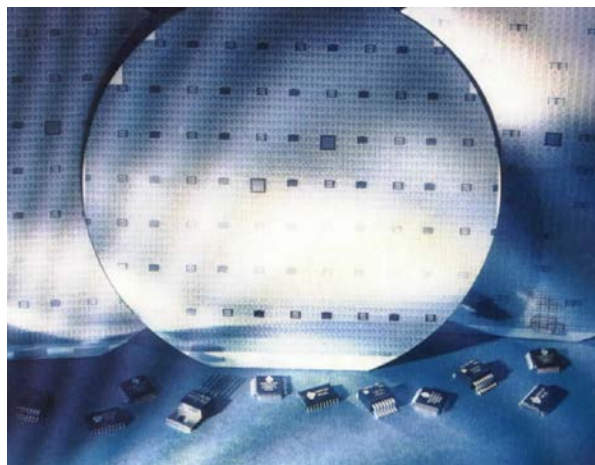
After fabrication, each chip on the wafer is tested to confirm that the electrical circuits function properly. Chips that do not work are marked with an epoxy resin by an automatic marking system. The computer that runs the marking equipment maintains statistics on the number of good chips per wafer, their location on the wafer, and the incidence of various types of failures. On-wafer testing need not be done in a cleanroom, because the chips have been protected in the passivation step.

#### Cutting

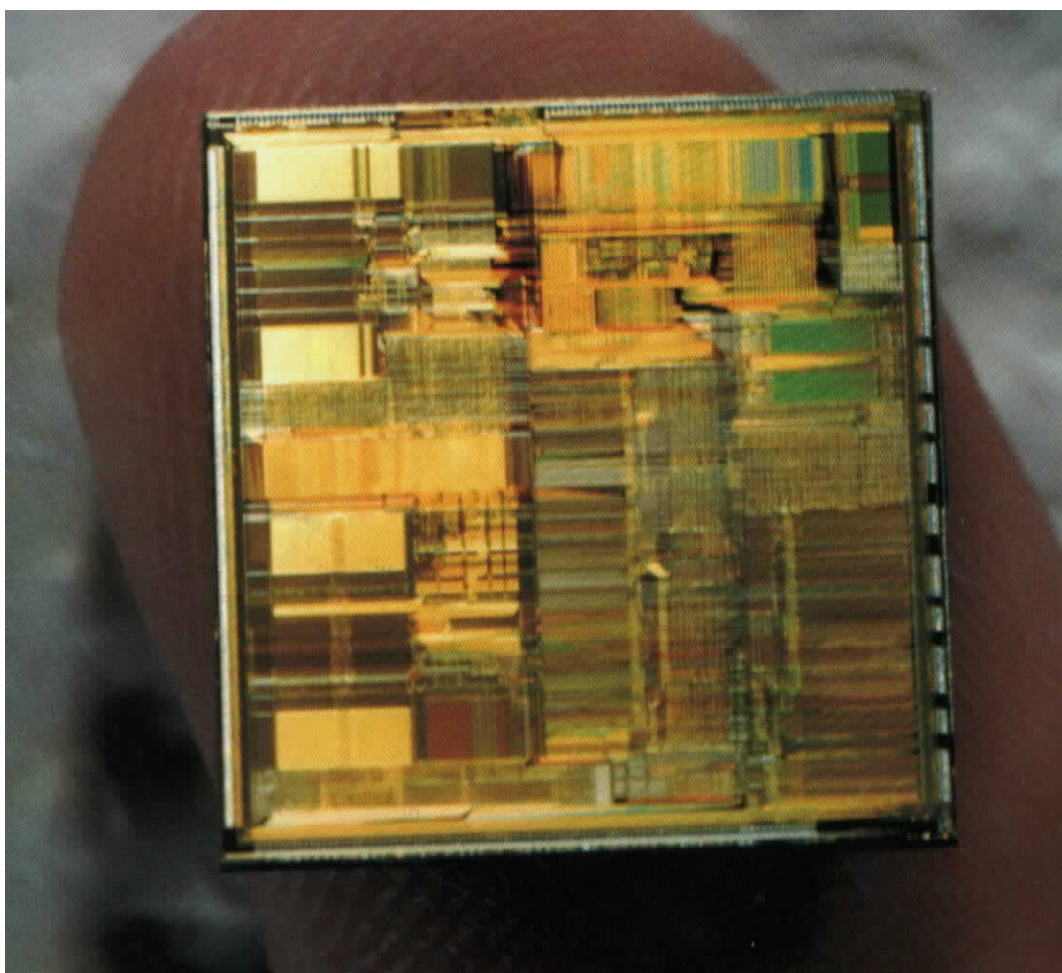
After testing and marking, the individual chips must be physically separated. Diamond scribing, laser scribing or diamond wheel wet sawing are the methods presently used. (See Figures 5 and 6.)

Diamond scribing uses a precisely shaped diamond-tipped scribe, which is drawn across the wafer surface. Laser scribing is the same except that a laser beam is used. The scribing causes an imperfection in the crystal structure, which allows the wafer to be bent and fractured along the scribed line.

Diamond sawing uses a high-speed circular diamond saw that either partially or completely cuts through the wafer. Water is used to keep the wafer cool during cutting and to wash the dust particles away.



**Figure 5.** Completed Wafer Before Dicing Into Individual Integrated Circuits (IC's). Courtesy of Cherry Semiconductor.



**Figure 6.** Finished Semiconductor Chip. Courtesy of Intel.

### Plating

Completed chips must have wire leads attached and must be mounted in metal frames. The wire leads and metal frames require plating to give certain characteristics to the completed chip. Metals, such as gold, nickel and platinum, are used as plating material.

The operation is typical of most plating operations using heated immersion tanks containing acids and other corrosives. Most equipment is standard and of plastic construction, however, there is occasionally some customized machinery.

Many semiconductor facilities hire outside vendors to plate their chips.

### **Packaging And Assembly**

Packaging and assembly involves setting the chips in protective packages and attaching the wire leads. First, the chips (dies) are attached to the package by a bonding process. The three common bonding processes are eutectic bonding, preform bonding and epoxy bonding.

Eutectic bonding is accomplished by depositing a layer of metal on the back side of the die, placing the die on the package, and heating the package above the eutectic temperature of the metal. This forms a bond between the die and the package.

Preform bonding is accomplished by placing a material (preform) on the package that adheres to both the package and the die, then heating the package until the preform melts and bonds to the die.

Epoxy bonding is accomplished by placing a drop of epoxy on the package and placing the die on it. The package is then baked at an elevated temperature to cure the epoxy.

Next, the electrical connections between the chip and the package leads are made in a process called wire bonding. This process uses either thermocompression bonding, ultrasonic bonding or thermosonic bonding.

Thermocompression bonding is accomplished by heating the package and applying pressure to form a bond between the wire and the bonding pads. Either the ball bonding or wedge bonding method is used. The ball bonding method feeds wire through a capillary tube, compresses it, and melts it using a hydrogen flame. The ball bonding method is used for bonding gold wire.

The wedge bonding method uses a wedge-shaped bonding tool and a microscope for positioning the chip package over the bonding pads. Wedge bonding is performed in an inert atmosphere, the most common being nitrogen.

Ultrasonic bonding uses a pulse of ultrasonic, high frequency energy to create a scrubbing action that forms a bond between the wire and bonding pad. This technique is typically used for bonding aluminum wire.

Thermosonic bonding is a combination of ultrasonic and thermocompression bonding techniques.

Other bonding techniques have been developed. These include flip-chip, solder bump, beam lead and film bonding; however, these techniques have not yet replaced wire bonding.

Completed chips must be encapsulated in a package that meets the mechanical, electrical, thermal, chemical and physical requirements associated with the application of the integrated circuit being made. Chips that will be part of process equipment to be used in a severe environment require the sturdiest packaging.

Semiconductor chips come in many different package types. The three most common are:

- **Radial Lead** - Made of an iron-cobalt alloy called Kovar. Uses hard glass seals and Kovar leads.
- **Flat Packs** - Uses metal-lead frames made of an aluminum alloy combined with ceramic, glass and metal components.
- **Dual In-Line Package** - These packages are the most common and are usually made of ceramic or molded plastic.

Molded plastic packages are produced by either transfer molding or injection molding, with transfer molding being the most common.

Transfer molding is accomplished by mounting the chips on untrimmed lead frames and placing them in molds. Powder or pellet thermosetting plastic material is melted in a pot and then forced under pressure into the molds. The plastic is typically a mixture of resins, hardeners and fillers.

Injection molding is accomplished by using either a thermoplastic or thermosetting compound that is melted in a cylinder and then injected through a nozzle into the mold.

### **Final Testing**

The completed chip must go through a final series of tests to confirm that it functions as designed. These tests include numerous electrical leakage and burn-in tests. Because of the large number and the complexity of the tests required, specially designed computer equipment is required.

The final packaging of a computer chip is classified according to its ability to isolate the chip from its environment. The two classifications are hermetically sealed (air tight) or nonhermetically sealed. To confirm the packaging classification, a leak test must be performed. Helium leak detection and radioactive tracer leak detection are the types of leak testing presently used.

Helium leak detection is accomplished by placing the completed chips in a pressurized helium atmosphere for a period of time. Helium penetrates through imperfections in the package, and a mass-spectrometer is used to detect the amount of helium leaking through the imperfections. Radioactive tracer leak detection uses the same method, except that a radioactive tracer gas, usually Krypton-85, is substituted for helium.

Burn-in testing is accomplished by placing the device in a temperature controlled oven for an extended period of time. The temperatures range from 250°F – 400°F (120°C – 200°C), and time periods range from a few hours to 1000 h, with 48 h being average.

Tested chips are marked for identification using either a rotary offset printer, ink-jet head, toner printer or laser marking system. Except for the laser system, the processes use solvent-based inks. After marking, the finished devices are packed in various containers for shipping.

### **Finished Chip Storage**

The completed chips are packaged for storage and shipping. They are first placed in plastic or cardboard containers, and then packed in cartons. Methods of storage include bulk, palletized, bin box, rack, carousel and automated storage/retrieval systems.

## **BUILDINGS AND UTILITIES**

### **Construction**

Cleanliness is so important in a modern semiconductor plant that entire facilities are now built from the ground up in a clean environment. It is equally important that a semiconductor facility stay clean long after it is built. So that construction materials do not contribute to contamination, totally noncombustible materials must be used everywhere possible.

For production buildings with clean areas, follow the construction requirements in NFPA 318, PRC.17.11.0 and PRC.17.11.1. Use only fire resistive or noncombustible construction materials for all other production buildings.

Use only noncombustible interior partitions, such as those made from steel, aluminum, concrete or masonry. For interior finish, use listed construction materials having a flame spread rating less than 25, and fuel contributed and smoke developed ratings less than 50, when tested in accordance with ASTM E84 (UL 723). Do not use plastic coverings or plastic wall panels.

For suspended ceilings and pipe insulation, including adhesives, use listed construction materials having a flame spread rating less than 25, and fuel contributed and smoke developed ratings less than 50, when tested in accordance with the ASTM E84. Do not use plastic ceiling grates or waffle slab knockouts.

Cut off raw materials and finished product warehouses and flammable liquids storage from other areas with 3 h fire rated fire walls. Protect openings with 3 h rated fire doors. Protect storage of flammable liquids in accordance with NFPA 30 and PRC.8.1.0.

Divide open areas with large property and business interruption values with walls of 2 h rated construction. Protect openings with 1½ h rated fire doors. Review business interruption (BI) values for areas with duplicate or multiple product lines. Where BI value for an area is large, separate product lines with 2 h rated walls and 1½ h rated fire doors.

Use interior compartmentation to reduce the damage from smoke, corrosive fumes, fire and water. Subdivide process steps to the greatest extent possible using noncombustible walls. Extend walls from the subfloor to the ceiling or roof, not just to the suspended ceiling.

Design walls to prevent the passage of smoke and other products of combustion by properly sealing floor, ceiling and panel joints. Seal wall, floor and ceiling penetrations, such as those for electrical conduit, piping and ducts, to prevent passage of products of combustion and spilled liquids.

Consider segregating the following important, high value equipment:

- Epitaxial Reactors
- CAD Systems
- Wafer-Steppers
- E-Beam Lithography Systems
- Diffusion Furnaces
- Ion Implanters
- Sputterers

Install electrical equipment in accordance with NFPA 70. Where flammable gases or liquids are handled, follow Section 500 of NFPA 70. Classify areas as Division 1 or Division 2 in accordance with NFPA 497.

## Cleanroom Layout

The most common cleanroom layouts are ballroom fabs, finger fabs, and bay and chase fabs. Ballroom fabs are large open cleanrooms with many different pieces of process equipment in the same area. This layout could expose many pieces of equipment to the same incident.

Finger fabs have alternating clean and dirty corridors with permanent walls. Each clean finger has only a few pieces of process equipment. In bay and chase fabs, each piece of clean equipment is in a small, modular bay and other equipment in semi-clean chases.

With the advent of cluster tools and mini-environments, fab layouts are always evolving. The relevance of fab layout to loss control is in the extent of damage an incident could cause in the cleanroom.

## Critical Utilities

Large losses can result when a semiconductor manufacturing facility loses a critical utility. For example, all chips in process can be damaged by a very short electrical power outage. Critical utilities include electricity, clean air, semiconductor gases and de-ionized water. These utilities must be reliably protected against loss. In addition, spare capacity should be available for each.

Supply electricity from two independent feeds. Design the facility's electrical distribution system to be capable of rerouting power if a transformer or distribution line is lost. Looping both primary and secondary electrical power supplies is preferred.

In addition to a back-up electrical feed and flexible distribution system, provide uninterruptible power supplies for process systems critically dependent on electrical power. Such systems include:

- Air handling systems

- Semiconductor gas control systems
- Flammable gas detection systems
- Automated chemical delivery systems
- Refrigeration systems
- Computer systems

Arrange and protect transformers, including ion implanter transformers, in accordance with PRC.5.4.5, PRC.5.9.2, PRC.5.9.3 and PRC.5.9.4. Protect all high energy electrical equipment in accordance with PRC.5.0.3.

Clearly mark all utility lines, and keep plans showing their locations up-to-date. Larger facilities can have buried electrical lines and buried piping for de-ionized water, nitrogen, oxygen and helium. Such facilities should implement strict procedures for digging to avoid damage to these services.

## **Air Handling Systems**

Air handling systems in semiconductor facilities play a vital role in limiting contamination spread during and after a fire or chemical spill. The HVAC, fume exhaust and smoke removal systems require special loss prevention and control features.

For clean areas, follow the requirements for air handling systems in PRC.17.11.0 and PRC.17.11.1. Use the following principles to evaluate the air handling design:

## **HVAC Systems**

Zone HVAC systems to conform to the compartmented areas.

Provide as many separate HVAC systems as practical for each cleanroom. Design and install the systems in accordance with PRC.17.11.0 and PRC.17.11.1.

Provide separate HVAC systems for the mask production, chip fabrication and on-wafer testing areas.

Use only noncombustible materials for ducts, connectors and appurtenances. Where plastic materials are required, follow the requirements of PRC.17.11.0 and PRC.17.11.1.

Use filters that meet UL 586. Meeting this standard involves more than just having a Class I filter that meets UL 900. It also requires that the filter, frame and mastic bond be tested as a unit. The UL 586 filter is the best filter from a loss potential standpoint.

Provide a high sensitivity, air sampling type smoke detection system for each zone. Place detectors in exhaust openings and in the recirculation duct.

Ducted recirculation systems are preferred over above-the-ceiling plenums.

## **Fume Exhaust Systems**

Fume exhaust systems carry corrosive, flammable, organic, pyrophoric and toxic vapors from process tools. The hazards of these vapors require a fume exhaust system with the following features:

- Captures all expected contaminant releases, using an air velocity of at least 200 ft/min (61 m/min).
- Exhausts 100% of the vapor-air mixture captured.
- Segregates fume exhaust systems for corrosive, flammable, organic and pyrophoric materials, and segregates any materials within the same category that can react with each other.
- Shuts down manually with no automatic interlocks.
- Uses ducts for the entire system with no ceiling or floor plenums.
- Routes ducts as directly as possible to a fume treatment system without passing through fire barrier walls.
- Operates duct system at a lower pressure than the surroundings.
- Uses locking type dampers.

- Has an emergency power source for blowers and fans installed in accordance with NFPA 70.

Use metal ducts for conveying all fumes that are not corrosive. For corrosive fumes, use ducts that have passed FM 4922, which tests duct integrity under fire conditions. **NOTE:** Ducts made from plastics that pass UL 2360 or FM 4910 must also pass the FM 4922.

### Smoke Removal Systems

Install a separate smoke removal system for each air handling zone. Follow the requirements in PRC.2.1.4. Design smoke removal systems to exhaust at least 3 cfm/ft<sup>2</sup> (0.9 m<sup>3</sup>/min/m<sup>2</sup>) of floor area in addition to the fume exhaust.

When smoke removal is accomplished through the HVAC system, design it to provide 100% exhaust when actuated by smoke detection equipment. Stop recirculation air fans automatically by smoke detector operation. Provide makeup air through the filtered makeup air system or from an adjacent clean zone.

### Exterior Protection

Provide an initial and a second fire protection water supply in accordance with PRC.14.0.1. Install private fire service mains and hydrants in accordance with NFPA 24 and PRC.14.5.0.1.

### Interior Protection

Install automatic sprinklers throughout all buildings. Regardless of construction, provide sprinklers above and below all open ceiling grates. Design sprinkler systems as follows:

**Process Areas, Subfabs And Air Plenums** – Provide automatic wet pipe sprinkler systems with a density of 0.20 gpm/ft<sup>2</sup> (8 L/min/m<sup>2</sup>) over 3000 ft<sup>2</sup> (279 m<sup>2</sup>) and installed them in accordance with NFPA 13 and PRC.12.1.1.0. Because of the high air flow rates, use quick response sprinklers with a 135°F (57°C) link in all cleanrooms and interstitial air plenums.

Below raised floors, provide either sprinkler protection or a gaseous agent extinguishing system actuated by air sampling smoke detectors. Also provide spill detection.

**Storage Areas** - Protect storage of finished chips as Group A plastics in accordance with NFPA 13. Design automatic wet pipe sprinkler systems for storage arrangements as follows:

- **Bulk, Palletized And Bin Box Storage** - Design sprinkler systems in accordance with NFPA 13 and PRC.12.1.1.0, and protect the storage in accordance with NFPA 13 and PRC.10.1.1.
- **Rack Storage** - Design sprinkler systems in accordance with Chapter 7-4 of NFPA 13 and PRC.12.1.1.0 and protect the storage in accordance with NFPA 13 and PRC.10.1.1.
- **Carousel Storage** - Sprinkler systems for carousel racks must be custom designed. The design must consider whether the racks rotate in a horizontal or vertical plane, the unit height, flue spaces between the units, whether the unit is open or enclosed, and the class of commodity stored. Refer to PRC.10.1.2.3.

Provide flue sprinklers every 10 ft (3 m) in height. Protect enclosed carousels with both a sprinkler system and a gaseous agent extinguishing system actuated by smoke detectors. Design carbon dioxide systems in accordance with NFPA 12 and PRC.13.3.1. Clean agent systems in accordance with NFPA 2001 and PRC.13.6.1.

In areas of high combustible loading, such as storage areas, provide interior hose connections and equip each with 75 ft (25 m) of 1½ in. (40 mm) woven-jacket lined fire hose and an adjustable spray nozzle. Arrange hose connections to remain in service if sprinkler protection for that area is shut off.

Install Class A, pressurized water, portable fire extinguishers throughout the facility in accordance with NFPA 10 and PRC.13.7.1.1. Use ordinary hazard spacing for extinguisher distribution. Provide Class B, gaseous agent, portable fire extinguishers in areas containing electronics equipment or flammable liquids. Do not allow dry chemical extinguishers in semiconductor facilities.

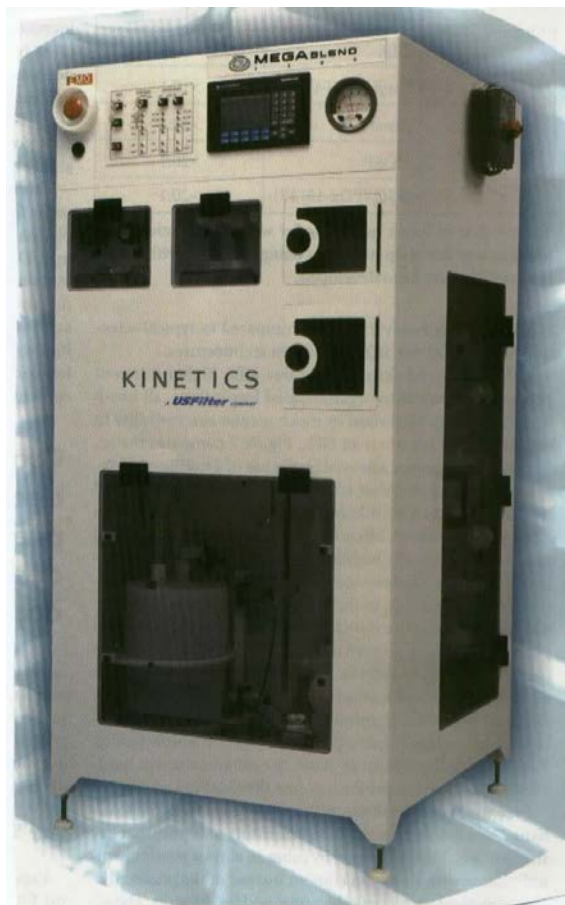


Transmit all fire and gas alarms to a constantly attended area. Install manual pull stations throughout the facility.

## PROCESS MATERIALS

Semiconductor manufacturing processes use many gases and liquids. Some of these materials are inert, but most present some type of loss exposure. The most commonly used gases are flammable or pyrophoric. Most of the liquids used are corrosive, combustible or flammable. Handling these materials safely requires good distribution system design and thorough operator training. (See Figure 7.)

See PRC.17.1.1.B for a description of some common chemicals used in chip fabrication.



**Figure 7.** Chemical Distribution System. Courtesy of KINETICS.

## Gases

Gases are major raw materials for a semiconductor manufacturing facility. The specific gases found at a facility depend on the products manufactured.

Gases are classed as pyrophoric, flammable, toxic, corrosive, oxidizing, radioactive and inert. Good loss prevention requires a strong management program to supervise gas handling for all classes of gas.

Most gases are handled in cylinders. Establish a cylinder management program that includes the following features:

- Written cylinder specifications for each gas.
- Cylinder inspection on arrival from the supplier. See PRC.7.0.5.2.

- Training program for all personnel handling cylinders.
- Emergency response team equipped and trained to handle cylinder and gas piping system malfunctions.

## Pyrophoric And Flammable Gases

Pyrophoric gases are gases that ignite spontaneously when exposed to air. Gases in this category usually are hydrides, such as silane and germane, or are metal alkyls, such as diethyl telluride and triethyl aluminum.

Silane is a general chemical term for any of the hydrides of silicon. The chemically simplest silane,  $\text{SiH}_4$ , is the most common pyrophoric gas used in the chip fabrication process. It is also one of the most dangerous.

Careless or improper storage and handling of silane can cause serious losses. A low pressure leak will probably ignite. A high pressure leak may not ignite initially but can create a gas mixture that will eventually explode. Either event creates a potential for major loss.

Gases can be handled in cylinders, near the tool needing the gases, or in bulk.

### Cylinders

Use only steel cylinders for semiconductor gases. Follow these guidelines whenever silane or other pyrophoric gases are being stored and handled:

- **Location** - Store all gases not in immediate use on a properly arranged and detached concrete pad.  
  
Store and dispense silane of greater than 5% concentration from stations outside the building. Detach the stations whenever possible, or put them near a blank masonry wall. If environmental considerations require, install an enclosure, a properly arranged, ventilated cabinet.  
  
Store cylinders of immediate gas supplies in dedicated, exhausted gas cabinets outside the cleanroom.
- **Piping** - Use double wall piping with inerting in the outer pipe and gas detection at the point of discharge of the inert gas.  
  
On gas lines, use high quality drawn, seamless 316 or 316L stainless steel tubing, as specified in ASTM A 269 or ASTM A 213. Piping should be welded, capable of withstanding  $1\frac{1}{2}$  times the maximum delivery pressure, and leak tested with helium to at least three times the maximum delivery pressure.  
  
Provide a minimum 4 in. (102 mm) diameter coil pigtail on connections between source cylinders to isolate vibration and to accommodate various cylinder heights.  
  
Where piping passes through walls or floors, protect it against chafing or movement. Properly reseal openings in fire walls. Run as much piping as possible in easily inspected and accessible locations.  
  
Pipe spent gas from tools to a dedicated fume exhaust system.
- **Fittings** - Bend tubing wherever possible to reduce the number of fittings required. Use tube benders to make all bends. Bends should not thin the tubing more than 15%.  
  
Locate fittings that are not under fume exhaust ventilation in easily inspected locations.
- **Valves** - Use only fail-safe gas delivery valves. These valves fail closed and require air pressure to remain open.  
  
Do not permit packed valves on systems containing silane. Use only valves constructed with metal-to-metal seals, such as packless diaphragm or bellows type valves.

Install excess flow valves in gas discharge lines in each cabinet. Stop gas flow upon detection of excess flow.

Provide an external emergency shut-off valve that can close the cylinder from outside the cabinet. Ventilate cabinets at a rate of 100 ft/min (31 m/min).

- **Regulators** - Seal weld fittings on the inlet and outlet of all regulators. Confirm that all unused ports were plugged and seal welded at the factory.

Confirm that all regulators have helium leak check certification.

- **Restricted flow orifices** - Provide a restricted flow orifice for each cylinder of pyrophoric or flammable gas. The orifice should limit flow to a maximum of 1 cfm (28 L/min).

Equip all regulators with a bonnet vent that can withstand a diaphragm rupture and carry the escaping gas to a suitable location.

Mount all regulators to prevent damage when the cylinders are changed.

- **Purge Systems** - Do not use the house nitrogen system for purging. Provide a dedicated purge source. Numerous losses have occurred where interconnections have been made to a house system or specific process system for purging.

Provide a dedicated purge gas cylinder for each class of gas (flammable, toxic or corrosive), except pyrophoric gases. Provide a dedicated purge gas cylinder for each **cylinder** of pyrophoric gas.

- **Gas Monitoring** - Monitor the inside of gas cylinder cabinets for escaped gas. Stop gas flow upon detection of any gas.
- **Ducts** - Use only noncombustible materials for the exhaust duct.

Route ductwork for silane out of the building as directly as possible, and keep it independent of any process ductwork.

Provide an emergency backup power supply for the duct system exhaust blower.

- **Sprinklers** - Equip gas cylinder cabinets with automatic sprinkler protection to prevent overheating of the cylinder in event of a fire.
- **Ventilation** - Supply constant ventilation through gas cylinder cabinets. Monitor the ventilation, and shut down the flow of gas upon loss of ventilation.
- **Point Of Use Fume Treatment** - Before fumes from a tool reach the fume removal system, pass them through burn boxes, treat them with thermal oxidizers, or dilute them. (See Figure 8.)

Design flammable gas lines to use the minimum possible pressure. Permanently label all lines, valves and functional components as to their use. Label all gas lines to indicate direction of gas flow and type of gas in the particular line.

Equip all systems containing flammable gases with pneumatically controlled panic shut-down devices installed as close to the cylinder as possible. Locate controls outside any cabinet.

Losses have occurred in gas systems with different purge system valving. To avoid operator confusion, provide identical valving on all gas purge systems in a facility.



**Figure 8.** Pyrophoric Effluent Treatment System. Courtesy of Evans Components, Inc.

Take these additional loss prevention measures for chlorine trifluoride and other comparably hazardous gases:

- Use piping materials that have been shown to withstand the corrosivity of this gas. Some fluorinated elastomers like Teflon™ and Halar™ are suitable for piping at low temperatures and flow. Except for brass, most metals are acceptable. Metals show the best stability, but they must be cleaned with solvent and passivated before use. Passivating involves purging vessels and piping with F<sub>2</sub> in nitrogen for anywhere from a day to a weekend before putting any chlorine trichloride in the system.
- Design the distribution system to keep the gas from condensing, because the liquid is even more damaging than the gas. Slope all lines down toward the supply cabinet and do not permit dead legs in the piping. Heat trace all lines to the tools.
- Shut off the gas supply on any of the following conditions:
  - Annular space pressure rise
  - Discontinuity in the heat tape
  - High or low heat tape temperature
  - High or low cylinder temperature
  - High or low cylinder pressure

### **Bulk Gas Storage**

Bulk gas systems, including those for silane, are becoming more common. Bulk silane systems can hold up to 100,000 times the volume at 100 times the pressure of conventional silane cylinders.

While a bulk silane system eliminates the hazards associated with having gas cylinders in the plant, it presents its own serious loss potentials. Contact AXA XL Risk Consulting early in the design stage if a bulk gas system is being planned.

## Flammable And Combustible Liquids

Store and handle flammable and combustible liquids in accordance with NFPA 30 and PRC.8.1.0. Keep dispensing operations in separate rooms with a minimum of 2 h fire resistance for walls, floor and ceiling. Do not store flammable liquids inside cleanrooms. Refer to NFPA 400 for guidance on storing and handling oxidizers and organic peroxides.

Protect operations that spray flammable liquids in accordance with NFPA 33 and PRC.9.2.3.1.

Store small amounts of flammable and combustible liquids in listed safety containers unless purity requires glass or plastic containers. Restrict glass or plastic containers to no larger than 1 gal (4 L), and limit the supply at the tool or in the cleanroom to a one day supply or 1 gal (4 L), whichever quantity is smaller.

Protect pass-through cabinets for supplying flammable liquids to cleanrooms with automatic sprinklers.

Use only noncombustible chemical delivery carts large enough to contain a spill of the largest container carried. Do not transport more than 50 gal (189 L) of liquids on one cart. Do not transport incompatible chemicals on the same cart.

Use only metallic pipe, tubing, fittings and valves on pressurized delivery systems for flammable or combustible liquids. Use welded joints where possible to minimize the use of valves and fittings in the delivery system. Use fittings only at the source container and the connection to the tool or work station. Provide the delivery system with pressure relief discharging to a safe location.

Hydrostatically test the installed system at 150% of the maximum working pressure for 2 h with no loss of fluid or reduction in pressure. Install automatic and manual shut-off valves at the liquid source, the tool and the source to the pressurizing medium or device. Connect automatic valves to suitably located shut-down stations and interlock them with the fire alarm for the area. The valves should fail closed on loss of power.

Many liquid delivery systems are automated. While automation reduces chances for human error, it increases chances that a problem will not be noticed quickly. A common arrangement for an automated delivery system includes a bulk tank, day tank and tool. Pumping from the bulk tank automatically fills the day tank. Vents on the day tank allow the liquid to be pumped into it. One loss exposure with day tanks is overfilling, which can cause extensive damage to ducts and process equipment.

To reduce chance of loss with automated liquid delivery systems, provide the following additional protection:

- Locate the system, including the bulk tank, pump, piping, day tank and tool, in an area with secondary containment. Do not put day tanks in clean areas. Provide manual shutoffs at points of use.
- Design the system to be fail-safe with manual reset only. Upon loss of power, excess temperature or high or low liquid level, close liquid supply valves, open vents, and turn off heat sources.
- Provide emergency backup power to the delivery control system.
- Provide excess flow protection or pre-set meters on bulk delivery systems.
- Install redundant liquid level sensors on the day tanks.
- Terminate day tank vents outside the building.
- If the tool or day tanks are electrically heated, use low energy heaters. Provide ground fault interruption, overcurrent protection and redundant high temperature sensors on heater circuits.
- Arrange the system to permit testing at regular intervals.

## Other Liquids

Many liquids used in semiconductor manufacturing are noncombustible, yet they still present a serious loss exposure to cleanroom operations. Acids used in etching can corrode work-in-process and process equipment if acid vapors reach unintended areas. Highly reactive peroxides used in developing can ruin chemicals and work-in-process if spilled. Even inert fluorocarbons can contaminate cleanroom operations if not properly contained. All liquid distribution systems must be properly designed, safely operated and well maintained to avoid problems.

## PROCESS EQUIPMENT

### Crystal Growing Furnaces

Crystal growing takes place inside a radio frequency (RF) heated vacuum furnace with an argon atmosphere. The furnace shell is water-cooled. A cooling water leak inside the furnace could cause a steam explosion, and the loss of cooling water could cause a burnout of the furnace shell. The puller is often hydraulically operated and, if the hydraulic fluid is combustible, presents a fire exposure.

When possible, use water-based hydraulic fluids. Equip the hydraulic system with a rupture disk, and pipe the discharge to a safe location. Provide a cooling water flow alarm to indicate a loss of furnace coolant, and provide an emergency cooling water connection. Refer to PRC.9.2.4.

### Semiconductor Cleanroom Tools

#### Deposition Furnaces

Deposition furnaces add the material to the wafer surface needed for the part of the circuit being made. Epitaxial reactors deposit the semiconducting layers, oxidation furnaces deposit the oxidizing layers, and sputterers deposit the conducting layers. Common deposition processes include chemical vapor deposition, electrochemical deposition and physical deposition. Laying down the conductive layers is also called metallization. See PRC.17.1.1.A for terminology pertaining to deposition processes.

#### Aligners

Properly positioning the mask is critical to producing acceptable chips. The mask is aligned with the wafer using a contact aligner, a proximity aligner, a mirror projection aligner or a wafer stepper (also called a step-and-repeat camera). Older aligning methods use ordinary light. Newer aligning methods replace light with electron beams, allowing smaller details to be drawn on the chips. See Figures 9 and 10.

Protect wafer-stepper enclosures with automatic gaseous agent extinguishing systems. Design and install the extinguishing systems in accordance with NFPA 12 and PRC.13.3.1, or with NFPA 2001 and PRC.13.6.1, as applicable.

Provide automatic gaseous agent extinguishing systems for electron beam lithography machines. Design and install the extinguishing systems in accordance with NFPA 12 and PRC.13.3.1, or with NFPA 2001 and PRC.13.6.1, as applicable.

#### Wet Benches

Wet benches are used in many of the washing, etching and cleaning processes in a semiconductor facility. Like many other pieces of semiconductor process equipment, wet benches have become larger and more complex. Due to the increasing size and weight of the items being processed, the benches are also more likely to be automated. Benches are also commonly made of plastic, and are not always designed to accommodate internal fire protection piping.

Plastic wet benches can now be 60 ft (18 m) long and weigh over 10 tons (9 tonnes). Wet benches commonly contain integral isopropyl alcohol tanks. Furthermore, enclosed head cases of automated benches usually contain the power and signal wiring for the expensive robotics needed to handle

300mm wafers. This wiring presents a new and hidden source of ignition for wet benches, and has already caused many fires. See Figures 11 and 12.

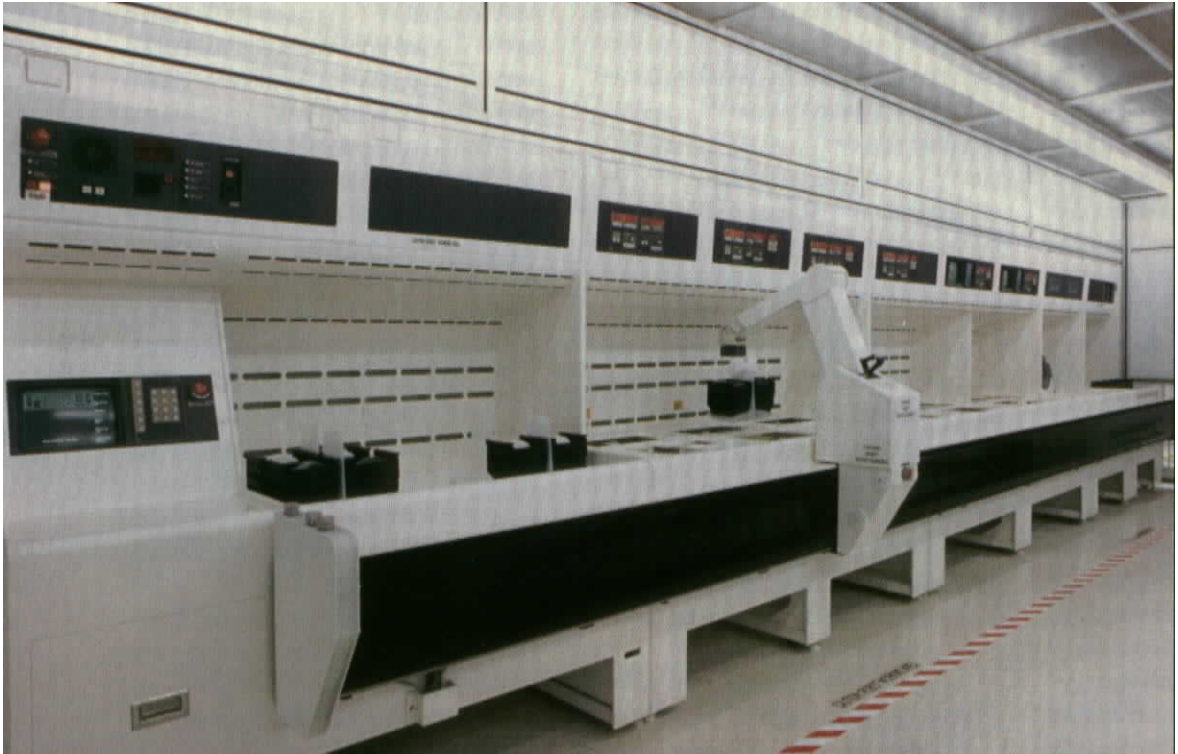


**Figure 9.** Fine Pattern Aligner. Courtesy of Canon.



**Figure 10.** Stepper (Step and repeat camera). Courtesy of Silicon Valley Group.



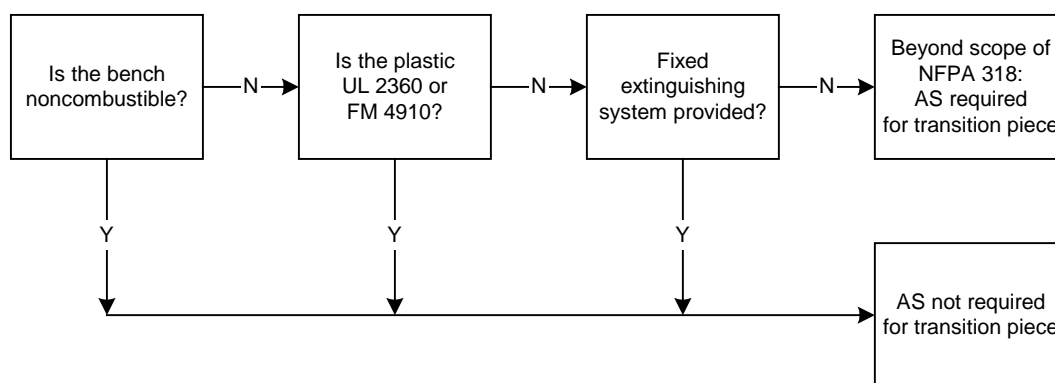


**Figure 11.** Large Automated Wet Bench. Courtesy of SCP Global Technologies.



**Figure 12.** A 300 mm Wafer. Courtesy of SEMATECH.





**Figure 13.** Decision Tree For Providing Sprinklers Within 2 ft Of Bench Ductwork Transition Piece.

These large and complex wet benches have high values and even higher business interruption potentials. They have built-in sources of ignition and very high combustible loading. For these reasons, specify that wet benches and any built-in storage tanks for flammable liquids be made of stainless steel. Allow only the parts of the bench that must come into contact with corrosive liquids to be made of plastic materials.

In addition, protect all wet benches with any plastics in construction, or handling any combustible or flammable liquids, in accordance with PRC.17.11.0 and PRC.17.11.1. Water, CO<sub>2</sub> and clean agents, such as FM-200, are all acceptable. Design clean agent extinguishing systems in accordance with NFPA 2001 and PRC.13.6.1. Design water mist systems in accordance with NFPA 750. Interlock extinguishing system actuation to shut off power to the bench. Confirm that the ceiling sprinkler system provides adequate coverage for the exterior of the bench.

Provide sprinklers within 2 ft (6 m) of the bench ductwork transition piece in accordance with Figure 13.

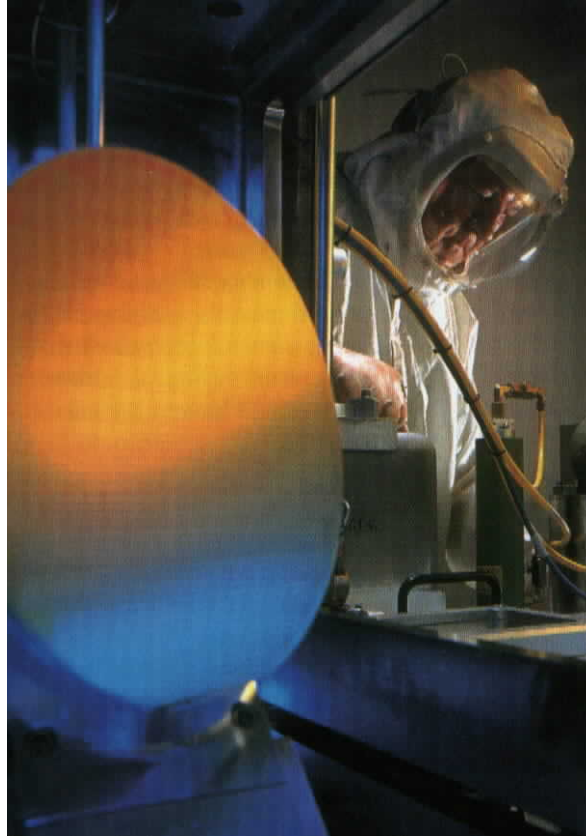
Two protocols are now available for testing combustibility characteristics of plastics intended for use in constructing wet benches, UL 2360 and FM 4910. The plastics that pass these tests have both low flame spread and low smoke developed ratings. They are referred to as less combustible plastics.

These new plastic formulations are the best now available from the standpoint of contamination potential from fire. Sprinkler protection is not required for benches made from these plastics, but detection and interlocks should be strongly considered. This is because even these plastics have a degree of combustibility. With a continuing ignition source, these plastics can burn and contribute to cleanroom contamination. See PRC.17.1.1.A, PRC.17.1.1.C and PRC.17.1.1.E.

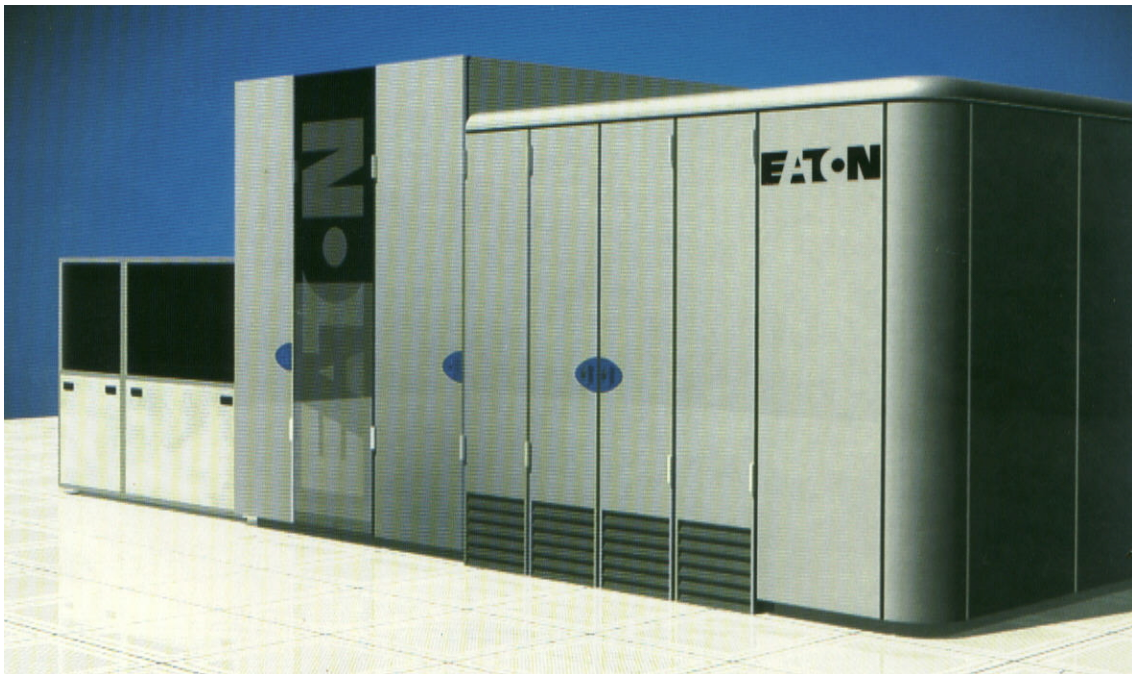
### Ion Implanters

A typical ion implanter is contained in an enclosure with approximate dimensions of 10 ft by 20 ft by 5 ft high (3 m by 6 m by 1.5 m high). A cleanroom used for ion implanting may contain up to 8-10 of these enclosures. See Figures 14 and 15.

Ion implanter enclosures usually contain cylinders of semiconductor gases in gas cabinets, tubing for transfer of the gases, an ion implant chamber (electric furnace) and a transformer. In the past, these transformers have been the dry type but oil-filled transformers are now being supplied. Most losses in ion implanters have involved the transformer.



**Figure 14.** Ion Implanter. Courtesy of Varian.



**Figure 15.** Ion Implanter Enclosure. Courtesy of Eaton Corporation.

To reduce chance of severe loss in the enclosure, use only dry type transformers for ion implanters. The next choice is to use transformers with less flammable dielectric fluid. Whenever possible, locate these transformers outside the cleanroom, preferably in the subfab area. Always locate oil-insulated transformers in a vault outside the cleanroom.

Implant gases are often supplied in small “lecture” cylinders. They are available in the Safe Delivery Source (SDS) type delivery systems designed to minimize chance of catastrophic gas release.

### Diffusion Furnaces

Diffusion furnaces can be in either the horizontal or vertical configuration (see Figure 16). They contain long quartz tubes with controls for temperature monitoring. Provide high temperature alarms and excess temperature cut-outs for these furnaces.

Depending on the dopant, diffusion furnaces make use of many different gases. Store and handle hazardous gases in accordance with this PRC Guideline. Store and handle oxygen in accordance with NFPA 55. Whenever the furnaces use hydrogen, provide hydrogen gas detection. Interlock it to alarm at 22% LEL and shut down the gas supply at 40% LEL.

Chlorine trifluoride is becoming more commonly used to clean the tubes of diffusion furnaces. See the section on Process Materials for safe handling of this dangerous and highly reactive chemical.



Figure 16. Vertical Diffusion Furnace. Courtesy of ASM.

### Vacuum Pumps

Vacuum pumps are found in many areas of a semiconductor facility. Processes, such as crystal growing, plasma etching, sputtering, evaporation, ion implantation, low pressure CVD, plasma enhanced CVD, plasma stripping, silicon epitaxy and ion milling, rely on a high quality vacuum environment.

The five kinds of pumps used in the semiconductor industry are mechanical rotary pumps, blowers, diffusion pumps, turbomolecular pumps and cryogenic pumps. The two basic classes of pumps are oil pumps and dry pumps.

Oil pumps are more often involved in losses than dry pumps. Typically, oil vapors in the pump exhaust are deposited in the exhaust duct. If allowed to accumulate, the oil becomes a major fire hazard. To reduce this hazard, use less flammable type hydraulic oils, such as Fomblin.

Loss control for oil pumps requires a complete preventive maintenance program that includes inspection of pump exhaust piping, regular oil changes, inspection and routine replacement of internal seals and O-rings, and thorough inspection of all pump orifices. Ensure that exhaust side ductwork is properly sized with limited direction changes. Provide an oil removal device in the discharge and confirm that it is working properly. To reduce costly down time, keep on site a supply of spare pump parts, as well as spare pumps.

Dry pumps do not use oil except for bearing lubrication. They are much less hazardous than oil pumps and should be the only type used for systems handling pyrophoric gases, flammable gases or flammable vapors; or for systems with high oxygen concentration. Provide dry pumps in pyrophoric, flammable or oxygen service with a nitrogen purge interlocked with the tool startup.

### **Spinners**

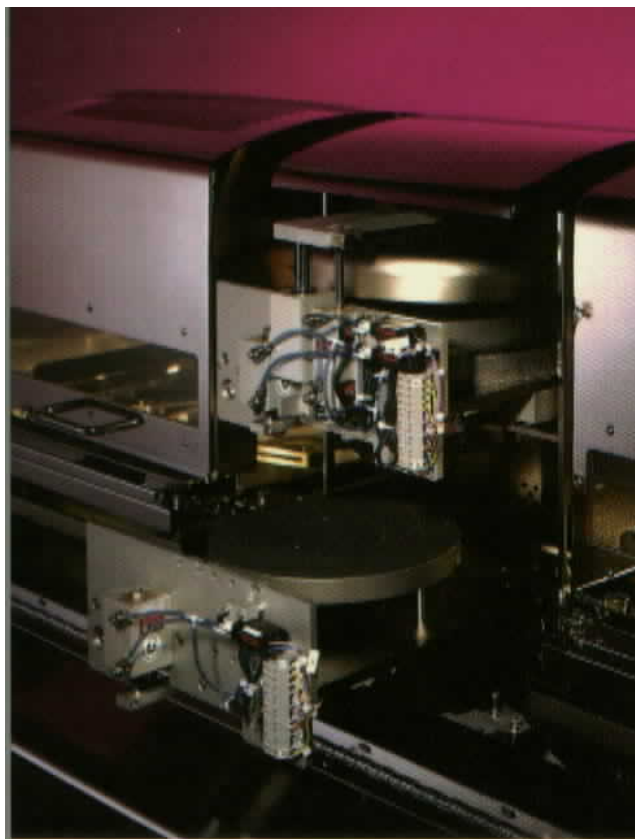
A spincoater (spinner) is a machine that applies hexamethyl disilazane (HMDS) and photoresist to the wafers to start the lithography process. HMDS is flammable, and most photoresists are either combustible or flammable. See Figure 17.

### **In-Process Wafer Handling**

Wafer storage and transport can be either manual or automated. Manual wafer handling introduces few additional loss prevention concerns. Automated wafer handling typically uses stockers and/or Front Opening Unified Pods (FOUPs).

A stocker is an enclosure for holding and transporting wafers between processing steps. The wafers are set in holders called boats, which slide into and out of the stocker for each step. A stocker can hold several hundred boats. The wafer boats are usually made of plastic.

Use stockers of noncombustible construction only. Since the wafer boats that go in the stockers are plastic, install sprinkler protection inside the stockers. If the electronic controller for the stocker is outside the area and enclosed by noncombustible partitions, high sensitivity smoke detection is adequate inside the stocker.



**Figure 17.** Wafer Spinner. Courtesy of Silicon Valley Group.

A FOUP is a more modern wafer storage and transport system. It holds larger wafers than a stocker holds, and it does not require boats. This increases the amount of wafers in process exposed to contamination. FOUPS are also usually made of plastic, further increasing the potential for contamination in the cleanroom. Protect FOUPS in accordance with Figure 18. Figures 19 and 20 show two types of FOUP.

### **Plastic Solution Tanks**

Plastic solution tanks are used for cleaning and etching. The tanks are set into wet benches and may even be an integral part of them. The solutions in the tanks are heated because the contaminants being removed from the items being cleaned are more soluble in hotter liquids.

Heated tanks present a serious loss potential, particularly in plastic tanks. Design and install heating systems for plastic tanks in accordance with PRC.9.5.1.

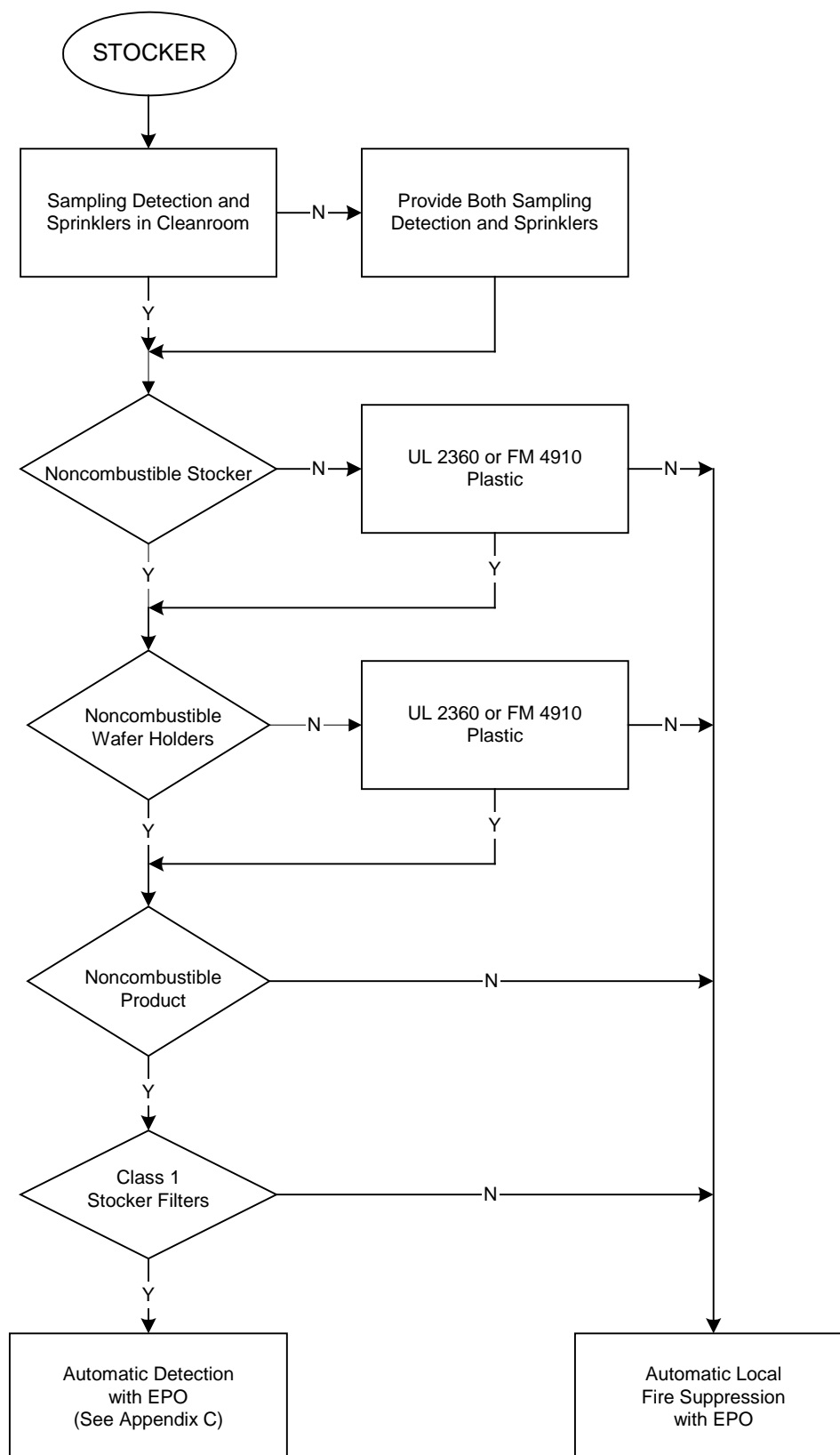
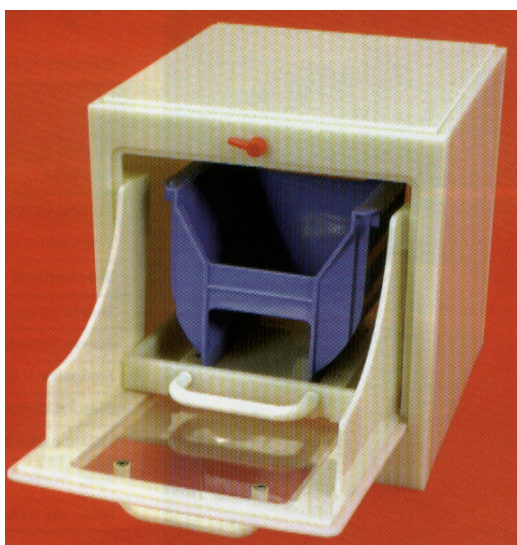


Figure 18. Decision Tree For Stocker/FOUP Protection.





**Figure 19.** Front Opening Unified Pod (FOUP). Photo courtesy of Daifuku and Fluoroware.



**Figure 20.** Front Opening Unified Pod (FOUP) Made Of Halar. Courtesy of Compression Polymers Group.

### **Environment “Burn-In” Ovens**

Provide an overtemperature interlock to shut down the oven. Install sprinklers in large, walk-in style ovens. Design and install the sprinkler system in accordance with NFPA 13 and PRC.12.1.1.0.

### **Wire Bonders**

Provide overtemperature controls for all heating units, and arrange them to shut off power to the heater.

## Hydrogen Atmosphere Sealing Ovens

Equip the hydrogen gas supply line with two automatic safety shut-off valves, a manual shut off valve and an emergency remote shut-off switch. Provide interlocks to prevent the admission of hydrogen gas prior to purging and heating the oven, and to prevent the opening of the oven until hydrogen is shut off and a post-purge is accomplished. Arrange the hydrogen supply line in accordance with NFPA 86 and NFPA 2.

## Mini-Environments

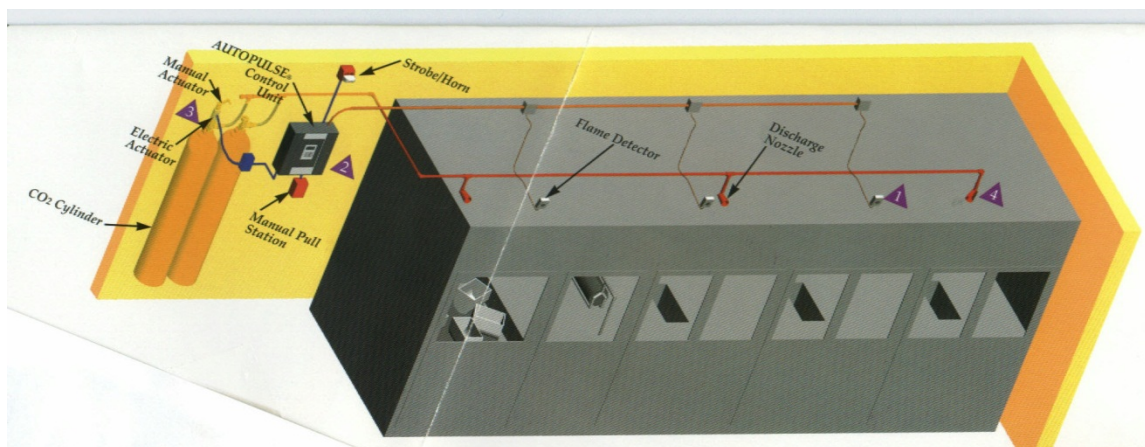
Mini-Environments are tools or group of tools enclosed for the purpose of keeping the required level of air cleanliness in the enclosure without having to keep an entire cleanroom at that level of cleanliness. Mini-environments pack large values into small areas and increase both property and business interruption loss potentials.

Protect mini-environments with fixed extinguishing systems. See Figure 21.

## Auxiliary And Support Equipment

### Computers

The semiconductor industry uses computers to design circuits, make masks, test chips, and control many other semiconductor processes. Keeping the computers up and running is essential to producing the chips.



**Figure 21.** Typical CO<sub>2</sub> Layout For A Wet Bench Mini-Environment. Courtesy of Ansul Fire Protection.

Provide automatic gaseous agent extinguishing systems beneath raised floors of computer installations and test areas. Design and install the extinguishing systems in accordance with NFPA 12 and PRC.13.3.1, or with NFPA 2001 and PRC.13.6.1, as applicable.

Back up all computer programs, including those for circuit design and wafer testing. Store the backup programs off-site, and keep them up to date. Protect computers in accordance with NFPA 75 and PRC.17.10.1.

### Plastic Molding Machines

Equip the melting pots with high temperature cutouts. Use noncombustible, water-based hydraulic fluid or less flammable hydraulic fluid as defined in PRC.9.2.4.

### Radioactive Tracer Leak Detectors

Locate these leak detectors in rooms designed to contain radiation leaks.

### Finished Product Storage

Install a smoke detection system in finished product storage areas. Projected beam style detectors are preferred when the clearance between top of storage and the ceiling exceeds 10 ft (3 m).



Design and install the smoke detection system in accordance with NFPA 72 and PRC.11.1.1.0.

### Thermal Oxidizers

Regenerative thermal oxidizers (RTOs) concentrate dilute volatile organic compounds (VOCs) and remove them from the cleanroom exhaust airstream. They return the purified air to the cleanroom supply. These oxidizers are necessary for complying with environmental laws. Figure 22 shows a regenerative thermal oxidizer. Locate heat sources for RTOs in areas that are not subject to contamination.

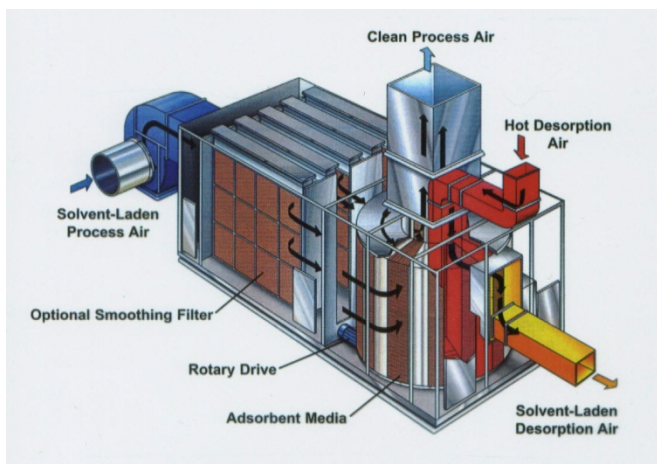


Figure 22. Typical Regenerative Thermal Oxidizer (RTO). Courtesy of Durr.

### Waste Containers

Throughout production areas, use listed waste containers that contain and suffocate an internal fire.

## MANAGEMENT PROGRAMS

Develop and implement written management programs for loss prevention and control as specified in AXA XL Risk Consulting's *OVERVIEW*. A high percentage of semiconductor processes take place in cleanrooms. Tailor management programs for cleanrooms in accordance with PRC.17.11.0. Tailor programs for the entire semiconductor facility as specified in the following areas:

### Maintenance

Develop and implement preventive maintenance schedules for all process equipment. The schedules should take into account the temperatures and chemicals that could expose each piece of equipment. Equipment exposed to higher temperatures or corrosive materials may require more frequent maintenance.

While operators can often tell when maintenance is needed on the equipment they operate, no one can point out when unattended equipment needs unexpected maintenance. Therefore, schedule more frequent preventive maintenance for unattended equipment, such as automated chemical delivery systems.

The preventive maintenance system should include equipment for providing utilities. Such equipment includes transformers, pumps, compressors, motors and fans. Refer to PRC.5.9.1, PRC.6.5.2 and PRC.7.0.5.2.

### Operator Training

Make sure operators are aware of the hazards presented by the materials and process equipment they are working with, and that they understand the importance of running the process safely. Teach

operators how to safely set up, start and shut down automated processes. Also teach them how to respond to emergencies.

### **Pre-emergency Planning**

Develop pre-emergency plans that minimize exposure of uninvolved clean areas. Educate the fire department and any other emergency response teams in these plans.

Develop cleanup plans and train employees how to implement them. Inform the restoration companies that may be contacted in an emergency of the chemicals used so they may be best prepared to respond. Also refer to PRC.16.5.

### **Hazardous Materials**

Analyze all materials to be used in the facility. Check these materials for consistency in physical and chemical properties, including purity. Check all possible combinations of materials for the degree of hazard the combinations present.

### **Process Hazard Evaluation**

Review all systems used for storing, conveying and dispensing materials. Check the compatibility of the piping systems and process equipment with the chemicals they handle. Determine where spilled or leaking chemicals will go and design rooms and processes to avoid damage from such incidents.

Review all processes and process equipment. Factor the results of risk-based analysis into materials choices. For example, when comparing the cost of plastic and steel wet benches, consider the chance of fire and its consequences. Similar considerations apply to choosing construction materials, transformer types and process chemicals.

### **Housekeeping**

Clean up any spills immediately. Determine the cause of spills or leaks, and fix the problem before restarting the equipment.

Keep combustible and flammable materials to an absolute minimum throughout the facility at all times. Prohibit temporary storage of any of these materials near any expensive stock or equipment.

## SEMICONDUCTOR GLOSSARY

**Aligner** A machine that positions the wafer for exposure to the mask pattern. Also see **Contact Aligner**, **Projection Aligner**, **Mirror Projection Aligner** and **Stepper**.

**AMHS** Automated Material Handling System

**Annealing** Heating wafers to approximately 600°C (1100°F) to stabilize the semiconducting properties of the wafer base material.

**APCVD** Atmospheric Pressure Chemical Vapor Deposition

**ASIC** Application-Specific Integrated Circuit

**AWB** Automated Wet Bench

**AWS** Automated Work Station (another term for wet bench)

**Ballroom Fab** A style of fab having all the wafer processing equipment in one large open cleanroom. Also see **Fab**, **Bay and Chase Fab**, and **Finger Fab**.

**Bay and Chase Fab** A style of fab with clean equipment in small, modular bays and other equipment in semi-clean chases. Also see **Fab**, **Ballroom Fab** and **Finger Fab**.

**BCDS** Bulk Chemical Delivery System

**BGA** Ball Grid Array

**BIOS** Basic Input/Output System

**Boat** See Wafer Boat.

**BOE** Buffered Oxide Etch

**Burn Box** A pyrophoric/air reaction system for safely disposing of excess pyrophoric gases at the point of use.

**CAD** Computer-Aided Design

**CDS** Chemical Delivery System

**CGA** Compressed Gas Association

**Chemical Delivery System** The system that stores semiconductor-processing chemicals and delivers these chemicals to tools in the cleanroom. For gases, this includes cylinders, cabinets, valving and piping to the tools. It could also include piping to bulk gas systems. For liquids, this includes bulk tanks, pumps, days tanks and associated valving and piping. Also see **Safe Delivery Source**.

**Chemical Mechanical Polishing** A polishing step that smoothes the wafer surface flat to achieve uniform thickness in the layer just deposited. Also see **Planarization**.

**Chemical Vapor Deposition** A process that deposits the desired chemicals on the wafer surface. This includes the three types of layering steps: **Epitaxy**, **Oxidation** and **Metallization**. Also see **Physical Vapor Deposition**.

**Chip** A semiconductor-based electronic circuit or group of circuits made for use in computers and other automated products. Many such chips are processed on each semiconductor wafer. Also called an integrated circuit (**IC**).

**Cleanroom** A room in which the concentration of airborne particles is controlled to specified limits. Cleanrooms include the areas below raised floors and above ceiling grids if they are part of the air path and within the rated construction. Also see Fab, Ballroom Fab, Bay and Chase Fab, and Finger Fab.

**Cluster Tool** Any cleanroom tool that performs several sequential processes on wafers. The parts of this type of tool are usually arranged in a cluster that emanates radially outward from the center.

**CMOS** Complementary Metal Oxide Semiconductor

**CMP** Chemical Mechanical Polishing

**Contact Aligner** An aligner that transfers the entire mask image to the semiconducting substrate by projecting light through the mask while it is in contact with the substrate. Also see **Aligner**, **Proximity Aligner**, **Mirror Projection Aligner** and **Stepper**.

**CPLD** Complex Programmable Logic Device

**CPVC** Chlorinated Polyvinylchloride

**Crystal** Crystals grown from semiconducting materials and intended to be sliced into wafers. The most common materials used to grow crystals are silicon and gallium arsenide. Other materials include gallium phosphide, gallium arsenide phosphide, germanium, indium phosphide, mercury cadmium telluride, sapphire and some of their mixtures.

**CSP** Chip Scale Package

**CUB** Central Utility Building

**CVD** Chemical Vapor Deposition

**Deposition** See **Epitaxy**, **Oxidation**, **Vapor Deposition**, and **Chemical Vapor Deposition**. Also see **APCVD**, **ECD**, **LPCVD**, **MOCVD**, **PECVD** and **PVD**.

**DI** De-Ionized (water)

**Diffusion** Diffusing dopant vapors onto wafers in quartz diffusion furnaces, usually in two steps. The first furnace operates at a temperature that allows a good supply of dopant material to be deposited on the wafer surface. The second furnace runs at a higher temperature to diffuse the dopant to the desired depth. This is one method of **Doping**.

**DIP** Dual In-Line Packaging

**DIW** De-Ionized Water

**Doping** Diffusing or implanting a wafer with materials having either more or fewer free electrons than the wafer base material. This controls the electrical properties of the circuits being made. Also see **Diffusion** and **Ion Implanting**.

**DRAM** Dynamic Random Access Memory

**DSP** Digital Signal Processing

**E-Beam** An electron beam used to make a mask for exposing wafers. The term is sometimes used to refer to an E-beam lithography machine. See **Lithography**.

**ECD** Electrochemical Vapor Deposition

**ECTFE** Ethylene Chlorotrifluorethylene

**EEPROM** Electronically Erasable Programmable Read Only Memory

**ELPD** Electrically Programmable Logic Device

**EPI** Epitaxy

**Epitaxy** Applying a single crystal film of semiconducting material to a wafer. The film is produced by chemical vapor deposition (CVD) of flammable and pyrophoric gases injected into an epitaxial reactor operating between 900°C (1652°F) and 1300°C (2372°F).

**EPO** Emergency Power Off Switch or Function

**EPROM** Erasable Programmable Read Only Memory

**ESD** Electronstatic Discharge

**Etching** Removing from a wafer any unpolymerized photoresist and the layer just beneath it. This is done by either chemical stripping or plasma etching. Chemical stripping uses acids and other chemicals to strip away the unpolymerized photoresist and is done at wet benches. Plasma etching is done in machines called plasma ashers.

**ETFE** Ethylene Tetrafluoroethylene

**EWSD** Early Warning Smoke Detection (See PRC.17.1.1.C)

**Fab** Wafer fabrication area. Also see **Cleanroom**.

**FAB** Fabrication facility

**FIB** Focused Ion Beam

**Finger Fab** A style of fab having alternating clean and dirty corridors with permanent walls. Also see **Fab**, **Ballroom Fab**, and **Bay and Chase Fab**.

**FOUP** Front Opening Unified Pod (a wafer storage and transport system for 300 mm wafers)

**FPGA** Field Programmable Gate Array

**FRP** Fiber Reinforced Plastic

**Fume Exhaust** High air flow duct systems that carry corrosive, flammable, organic, pyrophoric and toxic fumes from process tools to treatment equipment.

**Hazardous Production Material** Any solid, liquid or gas that has a degree-of-hazard rating in health, flammability or reactivity of Class 3 or 4 as ranked by NFPA 704, *Standard System For The Identification Of The Hazards Of Materials For Emergency Response*.

**Head Case** The compartment over the top of large modern wet benches that usually contains control wiring for running automated bench processes.

**HEPA** High Efficiency Particulate Air (Filters)

**HIPS** High Impact Polystyrene

**HMDS** Hexamethyl Disilazane (See PRC.17.1.1.B)

**HPM** Hazardous Production Material

**HSSD** High Sensitivity Smoke Detection (See PRC.17.1.1.C)

**IC** Integrated Circuit

**IFD** Incipient Fire Detector (See PRC.17.1.1.C)

**Immersion Heater** A heater immersed in a chemical bath on a wet bench to heat the liquid being used in that bench process.

**IMP** Ion Metal Plasma

**Ingot** Another term for **Crystal**.

**Integrated Circuit** A circuit or group of circuits integrated onto a semiconductor chip. Sometimes used interchangeably with **Chip**.

**Ion Implanting** Implanting dopants at room temperature instead of elevated temperatures. A high voltage electric field ionizes dopant ions and accelerates them to a high energy level. The ions are aimed at the wafer and become implanted in areas not protected by photoresist or by the oxide layer.

**Laminar Flow** Nonturbulent air flow, as is supplied from the ceilings of cleanrooms and the hoods of wet benches.

**Lapping** Removing the ridges formed when slicing the wafer and making its surfaces very smooth. In lapping, slurry passes over the wafers as they are held in large rotating plates.

**Layering** Adding the materials needed to build a chip. These include semiconducting, nonconducting and conducting materials. Layering processes include **Epitaxy**, **Oxidation** and **Metallization**.

**LED** Light-Emitting Diode

**Lithography** Using a mask to project the circuit image onto the wafer surface. Also see **Mask**, **E-Beam** and **Photolithography**.

**LPCVD** Low Pressure Chemical Vapor Deposition

**LSI** Large Scale Integration

**Mask** The mask is a thin, patterned sheet that shields portions of semiconductor material during wafer exposure. Each mask contains the pattern for a single layer of a circuit, so several masks are needed to make a completed circuit. Also see **Lithography**.

**MBE** Molecular Beam Epitaxy

**MCM** Multi-Chip Module

**MEBES** Manufacturing Electron Beam Exposure System

**MEMS** Micro Electrical Mechanical Sensor

**Metallization** Placing conducting material on the wafer to make the required electrical connections between the substrate and the layers of the chips.

**MIBK** Methyl Isobutyl Ketone (See PRC.17.1.1.B)

**Mini-Environment** An tool or group of tools enclosed for the purpose of keeping the required level of air cleanliness in the enclosure without having to keep an entire cleanroom at that level of cleanliness.

**Mirror Projection Aligner** An aligner that transfers the entire mask image to the semiconducting substrate by projecting light through the mask with a system of mirrors. The mirrors achieve a better depth of focus than in proximity aligning. Also see **Aligner**, **Contact Aligner**, **Proximity Aligner** and **Stepper**.

**MMX** Multi-Media Enhancement

**MOCVD** Metal Organic Chemical Vapor Deposition

**MOS** Metal Oxide Semiconductor

**MOSFET** Metal Oxide Semiconductor Field-Effect Transistor

**MUA** Make-Up Air

**NMOS** Negative-Channel Metal Oxide Semiconductor

**Oxidation** Depositing a nonconducting layer of silicon dioxide to protect the wafer surface from impurities and protect already completed layers from subsequent patterning and doping processes.

**Noncombustible** A material that, in the form in which it is used and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat. Materials that pass ASTM E 136, *Standard Test Method For Behavior Of Materials In A Vertical Tube Furnace At 750 °C*, are considered noncombustible. Building materials that pass ASTM E 84, *Test*

*Method For Surface Burning Characteristics Of Building Materials*, are considered noncombustible. See NFPA 220, *Standard On Types Of Building Construction*.

Plastics used in making semiconductor tools are sometimes called noncombustible if they pass either UL 2360, Standard Test Method For Determining The Combustibility Characteristics Of Plastics Used In Semiconductor Tool Construction, or FM 4910, FMRC Clean Room Materials – Flammability Test Protocol. In reality, these plastics are less combustible than conventional plastics and have a positive effect on loss potential, but they cannot strictly be considered noncombustible.

**Pass-Through** An enclosure, installed in a wall and having a door on each side, that allows chemicals, production materials, equipment and parts to be transferred from one side of the wall to the other without jeopardizing the controlled environment.

**Passivation** Applying a final coating to protect the finished chip from electrical and chemical environment hazards. Passivation is a CVD type process that coats the wafer surface with an oxide layer.

**PECVD** Plasma-Enhanced Chemical Vapor Deposition

**PEEK** Polyetheretherketone

**PFC** Perfluoro Compounds

**PGMEA** Propylene Glycol Monomethyl Ether Acetate (See PRC.17.1.1.B)

**Photolithography** A type of lithography that uses light beams. Also see **Lithography**.

**Photoresist** A light-sensitive chemical used to imprint the circuit pattern onto the wafer.

**Planarization** Polishing the wafer surface flat between layering steps. Usually done by **Chemical Mechanical Polishing**.

**Plasma Etchers** Etchers that use radio frequency to ionize oxygen in a vacuum chamber, enabling it to remove the photoresist.

**PLD** Programmable Logic Device

**PMOS** Positive-Channel Metal Oxide Semiconductor

**PMP** Polymethylpentene

**Polishing** See **Chemical Mechanical Polishing** and **Planarization**.

**PPO** Polyphenylene Oxide

**Proximity Aligner** An aligner that transfers the entire mask image to the semiconducting substrate by projecting light through the mask near but not in contact with the substrate. Also see **Aligner**, **Contact Aligner**, **Mirror Projection Aligner** and **Stepper**.

**PVC** Polyvinylchloride

**PVD** Physical Vapor Deposition

**PVDF** Polyvinylidene Fluoride

**Pyrophoric** Any gas that is spontaneously combustible with oxygen.

**RAM** Random Access Memory

**Restricted-Flow Orifice** A device located in the gas cylinder outlet valve body that restricts the maximum gas flow rate. AXA XL Risk Consulting recommends a maximum flow rate of 30 L/min (1.1 cfm).

**Reticle** The master image of a mask, used to transfer the pattern to master plates for making working masks.

**RHA** Return Air Handler

**RIE** Reactive Enhanced Etching

**RF** Radio frequency

**RFO** Restricted-Flow Orifice

**RODI** Reverse Osmosis De-Ionization

**ROM** Read Only Memory

**RTO** Regenerative Thermal Oxidizer

**Safe Delivery Source** Cylinders storing dopant gases by adsorbing them onto specially activated media at pressures below one atmosphere.

**SDS** Safe Delivery Source

**SECC** Single Edge Connecting Cartridge

**SEM** Scanning Electron Microscope

**Semiconductor** An element that conducts electricity under some conditions but not others. The most common semiconducting element is silicon. Others are gallium and germanium. Also see **Crystal**.

**SMIF** Standard Mechanical Interface (an interface for storing 200 mm wafers into stockers)

**Smoke** Airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion, along with the air entraining them.

**Spincoater** A machine that applies hexamethyl disilazane (HMDS) and photoresist to the wafers to start the lithography process.

**Spinner** Another term for **Spincoater**.

**Sputtering** A machine used in vacuum deposition and thin film metallization. See **Metallization**.

**SRAM** Static Random Access Memory

**Step and Repeat** Term for step and repeat camera, also called a **Stepper**.

**Stepper** An aligning machine that transfers small portions of a mask image to the semiconducting substrate, repeating the process until the entire mask image is transferred. This aligning method allows transferring the smallest circuit detail. Also see **Aligner**, **Contact Aligner**, **Proximity Aligner** and **Mirror Projection Aligner**.

**Stocker** An enclosure for holding and transporting boats of wafers between processing steps.

**Stripping** Removing unpolymerized photoresist in the etching process.

**Subfab** The area below a fab that contains ductwork, piping and other fab support equipment.

**TAB** Tape Automated Bonding

**TEOS** Tetraethylorthosilicate (See PRC.17.1.1.B)

**TMAH** Tetramethylammonium Hydroxide (See PRC.17.1.1.B)

**Tool** Any piece of process equipment used in making chips.

**Transition Piece** The piece that connects the duct outlet on the back of a wet bench to the fume exhaust system.

**ULPA** Ultrahigh Efficiency Particulate Air (Filter)

**UPW** Ultra Pure Water

**Vacuum Pump** A pump that pulls a vacuum on semiconductor processes that require it. Such processes include crystal growing, plasma etching, sputtering, ion implantation, LPCVD, PECVD, plasma stripping, and epitaxy.



**Vapor Deposition** See **Chemical Vapor Deposition**.

**VDF** Vertical Diffusion Furnace

**VESDA** Very Early Smoke Detection Apparatus (See PRC.17.1.1.C)

**VLF** Vertical Laminar Flow

**VLSI** Very Large Scale Integration

**VOC** Volatile Organic Compound

**Wafer** A slice from a semiconductor ingot that is made for fabricating chips.

**Wafer Boat** A container, usually made of plastic, designed for holding wafers during processing.

**Wet Bench** A hooded, ventilated workstation for washing, etching and rinsing chips in process. The benches often contain heated chemical baths.

**Wet Workstation** See **Wet Bench**.

**WIP** Work in Progress

**Workstation** An independent piece of equipment or a defined space in a cleanroom where a specific function, laboratory procedure or research activity occurs, usually involving hazardous production materials. The workstation could include connected cabinets, ventilation equipment, electrical devices, sensors for gases and other hazards, and related processing equipment.

**WSPM** Wafer Starts Per Month

**WSPW** Wafer Starts Per Week

## CHEMICALS USED IN CHIP FABRICATION

This appendix lists chemicals commonly used in chip fabrication processes – it is not intended to be a comprehensive list of chemicals used by the semiconductor industry. A given semiconductor facility could use many other chemicals. For additional information on toxic gases, see the following sites:

<http://www.city.palo-alto.ca.us/fire/business/tgogasmatrix.pdf>

<http://www.unidocs.org/un-015.html>

**Acetic Acid** ( $\text{CH}_3\text{COOH}$ ) Mildly corrosive liquid used in etching.

**Acetone** ( $\text{CH}_3\text{COCH}_3$ ) Flammable liquid used for cleaning.

**Aluminum** (Al) A solid metal used to form the electrical interconnections between chip components. It is usually applied in a deposition process called metallization.

**Ammonia** ( $\text{NH}_3$ ) Explosive, toxic gas used in vapor deposition and etching.

**Ammonium Hydroxide** ( $\text{NH}_4\text{OH}$ ) Oxidant liquid used for developing.

**Antimony** (Sb) A toxic, highly reactive solid used in doping. Commonly used in the form antimony trioxide.

**Antimony Trioxide** ( $\text{SbO}_3$ ) A toxic solid used as a dopant.

**Arsenic Pentafluoride** ( $\text{AsF}_5$ ) Toxic, corrosive gas used in ion implanting.

**Argon** (Ar) Inert gas used to maintain purity in almost every chip fabrication process.

**Arsenic** (As) A solid, toxic carcinogen used in ion implanting as **Arsenic Pentafluoride**. It can also be combined with Gallium to make **Gallium Arsenide** semiconducting material.

**Arsine** ( $\text{AsH}_3$ ) Flammable, toxic gas used in vapor deposition, epitaxy and doping.

**Boron** (B) A dopant that can be used in either solid or gaseous form. Commonly used Boron compounds include **Boron Nitride**, **Boron Trichloride**, **Boron Trifluoride**, **Boron Trioxide** and **Diborane**.

**Boron Nitride** (BN) A solid powder used in doping.

**Boron Trichloride** ( $\text{BCl}_3$ ) Toxic, corrosive gas used in etching and doping.

**Boron Trifluoride** ( $\text{BF}_3$ ) Toxic gas used in etching and doping.

**Boron Trioxide** ( $\text{BO}_3$ ) A solid powder used in doping.

**Butyl Acetate** ( $\text{CH}_3\text{COOCH}_2\text{CH}_2\text{CH}_2\text{CH}_2$ ) Flammable liquid used as a photoresist.

**Carbon Dioxide** ( $\text{CO}_2$ ) Inert gas used in vapor deposition.

**Carbon Monoxide** (CO) Flammable, toxic gas used in epitaxy and metallization.

**Carbon Tetrachloride** ( $\text{CCl}_4$ ) (Also called tetrachloromethane) Noncombustible liquid used in etching.

**Chlorine** (Cl) Toxic, corrosive gas used in etching.

**Chlorine Trifluoride** ( $\text{ClF}_3$ ) An extremely reactive, flammable and corrosive gas used for cleaning various semiconductor tool components.

**Chlorobenzene** ( $\text{C}_6\text{H}_5\text{Cl}$ ) Flammable liquid used as a photoresist.

**Chromic Phosphoric Acid** ( $\text{CrPO}_4$ ) Noncombustible liquid used in stripping.

**Copper** (Cu) A solid metal used to form the electrical interconnections between chip components. It is usually applied in a deposition process called metallization.

**Diborane** ( $\text{B}_2\text{H}_6$ ) Pyrophoric, toxic gas used in vapor deposition and epitaxy.

**Dichlorosilane** ( $\text{SiH}_2\text{Cl}_2$ ) Flammable, corrosive gas used in vapor deposition and epitaxy.

**Dimethylbenzene** – See **Xylene**.

**Dimethylzinc** [ $(\text{CH}_3)_2\text{Zn}$ ] Flammable, toxic gas used in vapor deposition.

**Disilane** ( $\text{SiH}_6$ ) Flammable gas used in vapor deposition.

**Ethanol** – See **Ethyl Alcohol**.

**Ethyl Alcohol** ( $\text{C}_2\text{H}_5\text{OH}$ ) (Also called ethanol) Flammable liquid used as a photoresist.

**Ethylbenzene** ( $\text{C}_6\text{H}_5\text{C}_2\text{H}_5$ ) Flammable liquid used as a photoresist.

**Ethyl Lactate** ( $\text{CH}_3\text{CH}_2\text{OCOOC}_2\text{H}_5$ ) Flammable liquid used as a photoresist.

**Ethylene Glycol Monomethyl Ether** ( $\text{CH}_3\text{OCH}_2\text{CH}_2\text{OH}$ ) Combustible liquid used as a photoresist.

**Formaldehyde** ( $\text{HCHO}$ ) Combustible liquid used in plating.

**Gallium** (Ga) A solid metal used in doping, often in the form **Trimethyl Gallium**. It can also be combined with Arsenic to make **Gallium Arsenide** semiconducting material.

**Gallium Arsenide** (GaAs) A semiconducting material sometimes used instead of **Silicon**.

**Germane** ( $\text{GeH}_4$ ) Flammable, toxic gas used in vapor deposition and epitaxy.

**Germanium** (Ge) A solid semiconducting material. Also combined with hydrogen to make **Germane**.

**Helium** (He) Inert gas used for purging tools and flushing chemical distribution piping.

**Hexamethyldisilazane** [ $(\text{CH}_3)_3\text{SiNHSi}(\text{CH}_3)_3$ ] Flammable liquid used to improve adhesion of photoresist to the wafer.

**Hydrochloric Acid** (HCl) Corrosive liquid used in etching.

**Hydrofluoric Acid** (HF) Corrosive liquid used in etching.

**Hydrogen** ( $\text{H}_2$ ) Flammable gas used in most chip fabrication processes. Combined with **Silicon**, **Germanium** and other solids to make process gases like **Silane** and **Germane**.

**Hydrogen Chloride** (HCl) Toxic, corrosive gas used in oxidation and etching.

**Hydrogen Peroxide** ( $\text{H}_2\text{O}_2$ ) Oxidant liquid used in stripping.

**Hydrogen Selenide** ( $\text{H}_2\text{Se}$ ) Flammable, toxic gas used in ion implanting.

**Hydrogen Sulfide** ( $\text{H}_2\text{S}$ ) Toxic gas used in vapor deposition.

**Indium** (In) Solid used in doping. Commonly used in the form **Trimethyl Indium**.

**Isopropanol** – See **Isopropyl Alcohol**.

**Isopropyl Alcohol** [ $(\text{CH}_3)_2\text{CH}_2\text{O}$ ] (Also called isopropanol) Flammable liquid used for cleaning.

**Magnesium** (Mg) Combustible metal used as a target in ion implanting.

**Methanol** – See **Methyl Alcohol**.

**Methyl Alcohol** ( $\text{CH}_3\text{OH}$ ) (Also called methanol) Flammable liquid used for removing marker inks and in plating.

**Methyl Benzene** – See **Toluene**.

**Methyl Chloroform** – See **Trichloroethane**.

**Methyl Ethyl Ketone** ( $\text{CH}_3\text{COCH}_2\text{CH}_3$ ) Flammable liquid used in developing.

**Methyl Isobutyl Ketone**  $[(\text{CH}_3)_2\text{CHCH}_2\text{COCH}_3]$  Flammable liquid used for cleaning.

**n-Methyl Pyrrolidone** ( $\text{CH}_3\text{NCH}_2\text{CH}_2\text{CH}_2\text{CO}$ ) (Also called m-Pyrol, a trademark name) Combustible liquid used for cleaning.

**M-Pyrol** – See **n-Methyl Pyrrolidone**.

**Nitrogen** ( $\text{N}_2$ ) Inert gas used in oxidation, epitaxy and doping.

**Nitrogen Trifluoride** ( $\text{NF}_3$ ) Toxic gas used in etching.

**Nitrous Oxide** ( $\text{N}_2\text{O}$ ) Explosive gas used in vapor deposition.

**Oxygen** ( $\text{O}_2$ ) Oxidant gas used in oxidation, diffusion, vapor deposition and etching.

**Phosgene** ( $\text{COCl}_2$ ) Flammable, toxic gas used in epitaxy, doping and vapor deposition.

**Phenol** ( $\text{C}_6\text{H}_5\text{OH}$ ) Combustible liquid used in stripping.

**Phosphine** ( $\text{PH}_3$ ) Pyrophoric, toxic gas used in epitaxy, doping and vapor deposition.

**Phosphoric Acid** ( $\text{H}_3\text{PO}_4$ ) Corrosive liquid used in etching.

**Phosphorous Pentafluoride** ( $\text{PF}_5$ ) Toxic, corrosive gas used in ion implanting.

**Potassium Hydroxide** ( $\text{KOH}$ ) Oxidant liquid used in developing.

**Propanol** – See **Propyl Alcohol**.

**Propyl Alcohol** ( $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ ) (Also called propanol) Flammable liquid used for cleaning.

**Propylene Glycol** ( $\text{CH}_3\text{CHOHCH}_2\text{OH}$ ) Combustible liquid used as a photoresist.

**Propylene Glycol Monomethyl Ether Acetate** ( $\text{CH}_3\text{CHOHCH}_2\text{OH}$ ) Combustible liquid used as a photoresist.

**Silicon** ( $\text{Si}$ ) The most common semiconductor chip base material. Grown as elemental crystals for slicing into wafers. Also combined with other elements to make process gases such as **Dichlorosilane**, **Hexamethyldisilazane**, **Silicon Tetrachloride** and **Silicon Tetrafluoride**.

**Silicon Tetrachloride** ( $\text{SiCl}_4$ ) Pyrophoric gas used in vapor deposition, epitaxy and etching.

**Silicon Tetrafluoride** ( $\text{SiF}_4$ ) Toxic, corrosive gas used in ion implanting and etching.

**Sodium Hydroxide** ( $\text{NaOH}$ ) Oxidant liquid used in developing.

**Sulfur Hexafluoride** ( $\text{SF}_6$ ) Inert gas used in etching.

**Sulfuric Acid** ( $\text{H}_2\text{SO}_4$ ) Corrosive liquid used in etching.

**Tellurium** ( $\text{Te}$ ) Solid metal used in doping, often in gaseous form as **Tellurium Hexafluoride**.

**Tellurium Hexafluoride** ( $\text{TeF}_6$ ) Toxic gas used in doping.

**Tetraethylorthosilicate**  $[(\text{C}_2\text{H}_5)_4\text{SiO}_4]$  Combustible liquid used in vapor deposition.

**Tetrachloromethane** – See **Carbon Tetrachloride**.

**Tetramethylammonium Hydroxide**  $[(\text{CH}_3)_4\text{NOH}]$  Strongly basic liquid used in developing.

**Titanium** ( $\text{Ti}$ ) Combustible metal used as a target in ion implanting.

**Toluene** ( $\text{C}_6\text{H}_5\text{CH}_3$ ) (Also called methyl benzene) Flammable liquid used as a photoresist.

**Trichlorobenzene** ( $\text{C}_6\text{H}_3\text{Cl}_3$ ) Combustible liquid used as a photoresist.

**Trichloroethylene** ( $\text{CHClCCl}_2$ ) Combustible liquid used for cleaning wafers.

**Trichloroethane** ( $\text{CH}_3\text{CCl}_3$ ) (Also called methyl chloroform) Combustible liquid used for cleaning wafers.

**Trimethyl Aluminum** [(CH<sub>3</sub>)<sub>3</sub>Al] Toxic, pyrophoric liquid sometimes used to carry **Aluminum** for metallization processes.

**Trimethyl Gallium** [(CH<sub>3</sub>)<sub>3</sub>Ga] Toxic, pyrophoric liquid used to carry **Gallium** for doping processes.

**Trimethyl Indium** [(CH<sub>3</sub>)<sub>3</sub>In] Toxic, pyrophoric liquid used to carry **Indium** for doping processes.

**Tungsten Hexafluoride** (WF<sub>6</sub>) Corrosive gas used in vapor deposition.

**Xenon** (Xe) Inert gas used in etching.

**Xylene** [C<sub>6</sub>H<sub>4</sub>(CH<sub>3</sub>)<sub>2</sub>] (Also called dimethylbenzene) Flammable liquid used as a photoresist.

## FIRE AND SMOKE DETECTION FOR CLEANROOM TOOLS

Automatic fire or smoke detection should be provided for semiconductor process equipment that either handles combustible or flammable materials, or is itself combustible. Detection can be in the cleanroom air handling system, inside semiconductor cleanroom tools, or both.

Even the least combustible plastics, such as those meeting UL 2360 or FM 4910, can generate smoke when heated, can ignite, and can continue to burn if the ignition source is not removed. Therefore, detection should always be considered for equipment made from those plastics. However, the AXA XL Risk Consulting account team could accept tools without detection in individual cases where the following factors are favorable:

- Amount of plastic present
- Geometry of the plastic (inaccessible areas, enclosed compartments)
- Smoke release rate of the plastic
- Number and strength of potential ignition sources (wiring, heaters)
- Capacity of smoke removal system
- Proximity of other tools
- Value of work in process likely to be in the area
- Potential consequences of smoke release in the area
- Constant attendance by operators trained to limit smoke damage

Since small amounts of smoke can cause large amounts of damage in the semiconductor industry, smoke detectors should be as sensitive as possible. NFPA 318 requires air sampling type detectors in the return air stream to the cleanroom air handling system. However, any type of smoke detector with the required sensitivity at the specified air flow would be acceptable if so tested. Less sensitive types of detectors are suitable for other cleanroom applications. The types of detectors that might be used in cleanrooms include the following:

**Air Sampling:** Appropriately sized sampling tubes draw air from multiple sampling points into a central detector. This is the most sensitive type of detection system. Such detectors are very effective in cleanroom air handling systems, but they are not appropriate for wet benches or other areas with harsh (acidic) atmospheres. Air sampling detection systems are often referred to with the following acronyms:

**IFD** Incipient Fire Detector: The terminology used by SAFE Fire Detection, Inc. for their Cirrus Incipient Fire Detection System. It uses a cloud-chamber type central detector. This system was first manufactured by Environment One under the name Cirrus 90.

**VESDA** Very Early Smoke Detection Apparatus: The terminology used by Vision Systems for their very early smoke detection system. The central detector in this system uses a Xenon light source to measure particles in the sampled air. Sensitivity of this system is between 0.03% and 0.15% obscuration per foot. This system was first marketed by Fenwal.

**HSSD** High Sensitivity Smoke Detection. The terminology used by Fenwal for their AnaLASER system. This system uses laser light to sense smoke in the central chamber. Sensitivity is between 0.003% and 0.03% obscuration per foot.

**Duct:** Detectors for use inside ducts are designed to work at high air flows. These can be conventional spot-type ionization or photoelectric detectors mounted in an outside sampling box, projected beam type detectors mounted inside larger plenums, or air sampling detectors. Listings for

duct detectors specify the maximum airflow rate. Duct detectors, even the air sampling type, do not have the sensitivity to meet the requirements of NFPA 318.

In a cleanroom, any type of duct detector can be used in the make-up air plenum but high sensitivity air sampling type detectors must be used in the return air plenum.

**Spot Laser:** Spot-type laser detectors use laser light to sense very small concentrations of smoke. They are often referred to with the following acronym:

EWSD Early Warning Smoke Detection. The terminology used by Notifier for their VIEW system. Detector sensitivity is approximately 0.03% obscuration per foot. These detectors have not yet been tested for high air flow applications. They can be used in unventilated areas.

**NOTE:** The term EWSD is sometimes used generically to include air sampling type detectors, as well.

**Optical:** Optical fire detectors sense particular wavelengths of the light emitted by a flame. These include UV, IR and combination UV/IR detectors. Some of these detectors, called wide band, sense more than one wavelength in the UV spectrum. Optical detectors can be designed to sense the wavelengths of light expected of a fire in the particular materials being protected. For example, Fire Sentry, Sierra Monitoring and Detronics manufacture optical detectors specifically for wet bench plastics and solvents.

Optical detectors can also be used for detection of a silane flame. For some flames, including silane, the detector must be specific enough to pick up that chemical's flame signature.

**Linear:** Linear type heat detectors are suitable for inside wet bench head cases and for inside other cleanroom tool enclosures. One well-known linear type heat detector is called Protectowire.

Examples of locations and process equipment that might have detection systems are:

- Cleanroom return air plenum
- Cleanroom makeup air plenum
- Wet bench head cases, surfaces and interior compartments
- Mini-environment interiors
- Wafer tracker and spincoater onboard collection systems
- Electron beam exposure systems
- Ion implanter enclosures
- Stocker interiors
- Test enclosures

Activation of detection systems on tools should automatically shut down power to the tool and stop flow of any hazardous gases or liquids. This removes potential ignition and fuel sources. Fume exhaust systems should **not** be shut down.

## SEMICONDUCTOR-RELATED WEB SITES

**Cleanrooms** - News of contamination control, business and technology, conferences, exhibitions, and more.

<http://www.cleanrooms.com>

**CPUs, Past, Present and Future** - A presentation that looks at eight of the most influential processors from 1974-2000. From ZDNet News.

<http://www.zdnet.com/zdnn/special/javascript/futurecpu/futurecpu.html>

**European Semiconductor** - European semiconductor information, including companies, products, job openings and articles.

<http://www.eurosemi.co.uk/Esmainframe01.htm>

**How Microprocessors Work** - interactive site is based on a real-life exhibit installed in the Intel Museum

<http://www.intel.com/education/mpuworks/>

**Micromagazine** - Micro magazine is dedicated to defect reduction and yield enhancement strategies for the semiconductor and related advanced microelectronics manufacturing industries. Now in its 18th year of publication, Micro is recognized by readers as a leader in its field for its technical content as well as its industry news and product coverage.

<http://www.micromagazine.com>

**SEMATECH (SEMiconductor MANufacturing TECHnology)** – Originally created to reinvigorate the U.S. semiconductor industry, International SEMATECH has evolved into the world's premiere research consortium, recently entering into globalization with the formation of International SEMATECH from its original consortium, SEMATECH. Member companies cooperate precompetitively in key areas of semiconductor technology, sharing expenses and risk. Their common aim is to accelerate development of the advanced manufacturing technologies that will be needed to build tomorrow's most powerful semiconductors.

International SEMATECH's leading-edge work encompasses essential areas of semiconductor science, including lithography, interconnect, front end processes, advanced technology, manufacturing methods, and environment, safety and health. International SEMATECH also provides important resources to the semiconductor industry, including coordinating global standards for 300 mm manufacturing; enhancing relationships between manufacturers and tool suppliers; and developing application-focused statistical training for the industry. Additionally, International SEMATECH and its people play active roles in the Austin community through career programs with local schools, scholarship contributions, and various development and charitable programs.

<http://www.semtech.org>

**SEMI (Semiconductor Equipment and Materials International)** – A global trade association that represents the semiconductor and flat panel display equipment and materials industries. Founded in 1970 in the United States, SEMI has evolved into a worldwide organization committed to free trade and open markets. The primary goal of SEMI is to help its members expand their global marketing opportunities and improve access to their customers and industry, government and civic leaders. SEMI accomplishes this goal by providing its members with up-to-date, industry-specific information and educational resources needed to manage their company and market their products more effectively.



SEMI represents more than 2000 member companies worldwide whose combined products and services contribute more than \$65 billion to the world economy. The International Standards Program is one of the key services offered by SEMI for the benefit of the worldwide semiconductor industry. SEMI International Standards are a collection of globally applicable standards and safety guidelines to support the manufacture of integrated circuits and other semiconductor devices.

<http://www.semi.org>

**Semiconductor Industry Association (SIA)** - Trade association representing the U.S. computer chip industry.

<http://www.semichips.org/>

**Semiconductor International** – An Internet resource for the semiconductor manufacturing industry. Some of the products and services offered are:

- Search Product Database – Search an extensive collection of product descriptions, complete with photos and company addresses.
- View New Products – Find new product releases from the Semiconductor Industry.
- Search Company Database – Find companies, vendors, fabs, associations, reps, and distributors in the Semiconductor Manufacturing Industry with the SI search engine. Results from your query can include a company that matches your query, contact info, company website URLs, and product release information.
- Search Association Database – Find companies, vendors, fabs, associations, reps, and distributors in the Semiconductor Manufacturing Industry with the SI search engine. Results from your query can include a company that matches your query, contact info, company website URLs, and product release information.

<http://www.semiconductor.net>

**Semiconductor Online** - includes product releases, industry news, manufacturers, technology announcements, employment opportunities, and discussion forums.

<http://www.semicondutoronline.com>

**Semiconductors Network** - Professionals' site for the semiconductor and integrated circuits (ICs) industries. Investments, ratings, technical papers, reference materials, and discussions.

<http://www.semiconductors.net>

**Semiconductor Terms, Abbreviations and Acronyms** - Semiconductor terms defined: programs, processes, products, and technologies.

<http://rel.semi.harris.com/docs/lexicon/preface.html>

**SEMIREF** – A semiconductor reference site that includes announcements, company profiles, and links to over 400 manufacturers' sites. The links are updated every 72 hours.

<http://www.semiref.com>

**SEMI/SEMATECH** – See **SISA**.

**Semiworld** – A semiconductor industry organization with web site that includes:

- Information about the latest processes, materials and facilities from business journals.
- Schedule of semiconductor-related event like trade shows, exhibitions and seminars.
- Customized, advanced searches for processes, equipment, materials and companies to find information easily and effectively.

The web site also includes a glossary, journal and listings of career opportunities.

<http://www.semiworld.com>

**Silicon Zoo** - Gallery of creatures, doodles and other things etched on microprocessors, as revealed by photomicrography.

<http://micro.magnet.fsu.edu/creatures/index.html>

**Simple Course on Microprocessors** - join the world of high tech and create things that will amaze your friends and family. Course developed by engineer Kenneth Richardson.

<http://www.hkrmicro.com/course/micro.html>

**SISA (Semiconductor Industry Suppliers Association)** – Formerly SEMI/SEMATECH, became SISA December 1999. An association of primarily U.S. suppliers to the semiconductor industry of equipment, materials, software and services. SISA's vision is to cooperatively develop the technology and customer relationships required for success in the international marketplace.

<http://www.sisa.org/index.html>

**SSA (Semiconductor Safety Association)** – SSA was formed in 1978. An informal meeting of nine safety and health professionals desiring to exchange safety information has grown into an annual international conference attended by over 600 professionals representing virtually all high technology disciplines. SSA membership has grown to over 1000 members including several countries around the world. As our horizons have broadened, we continue to focus our efforts toward an established line of environmental, health and safety communications.

SSA is an organization dedicated to the prevention of workplace injuries and accidents through the sharing of safety and health information and the promotion of technological advances in high technology, safety and health. Since its founding, SSA has established itself as an international organization promoting the effective communication of safety, health and environmental information to the electronics and related high technology industries.

<http://www.semiconductorsafety.org>

**Transistorized!** - learn how clashing egos and top secret research went into the invention of the transistor, perhaps the most important invention of the 20th century.

<http://www.pbs.org/transistor/>

**Underwriters Laboratories** - UL directory access, as well as summary information on UL standards (in particular No's 586, 900, and 2360 as they relate to the semiconductor industry.)

<http://www.ul.com>

**Webpedia** – An Internet resource for the computer industry with definitions, acronyms and encyclopedia. A search engine is provided.

<http://www.webpedia.com>

**Wikipedia** – An Internet encyclopedia of sorts.

[http://en.wikipedia.org/wiki/Semiconductor\\_device\\_fabrication](http://en.wikipedia.org/wiki/Semiconductor_device_fabrication)

Also see the list of other web-based references noted on the Wikipedia website below:

- [Howstuffworks' semiconductor page](#)
- [Semiconductor Concepts at Hyperphysics](#)
- Semiconductor OneSource [Hall of Fame](#), [Glossary](#)
- [Principles of Semiconductor Devices](#) by Bart Van Zeghbroeck, University of Colorado. An online textbook]
- [US Navy Electrical Engineering Training Series](#)
- [NSM-Archive](#) Physical Properties of Semiconductors]
- [Semiconductor Manufacturer List](#)
- [ABACUS](#) : Introduction to Semiconductor Devices – by Gerhard Klimeck and Dragica Vasileska, online learning resource with simulation tools on [nanoHUB](#)

- [Organic Semiconductor page](#)
- [DoITPoMS Teaching and Learning Package- "Introduction to Semiconductors"](#)

## THE UL 2360 TEST

Until recently, the only test for evaluating the combustibility of cleanroom plastics was the FM Approvals Test Standard 4910. This test measures fire characteristics in a specially modified calorimeter. Fire propagation, smoke damage and corrosion damage indices are then calculated from the measurements. It has been found that materials with a fire propagation index of less than 6 in this test are not self-propagating in the refereed Parallel Panel test.

As the search for better plastics escalated, numerous plastics manufacturers expressed the need to test their own products during development. They were not able to run the FM 4910 test because the nonstandard test apparatus is not readily available and the test results were not reproducible. In addition, the test is complex and expensive. At the semiconductor industry's request, AXA XL Risk Consulting and UL teamed up to explore whether a simple, reproducible test using standard apparatus could be developed. The ASTM E1354 test method for the cone calorimeter was selected for investigation.

With input from the semiconductor industry, AXA XL Risk Consulting and UL decided to base the classification system resulting from the new test on fire propagation and smoke damage properties.

The project was divided into 6 tasks as follows:

1. Characterize the Parallel Panel test ignition source.
2. Conduct Parallel Panel tests on representative plastics.
3. Conduct ASTM E1354 cone calorimeter tests on the same plastics.
4. Correlate Parallel Panel and cone calorimeter test results.
5. Develop a classification scheme for the combustibility of semiconductor plastics.
6. Develop a UL standard for classifying semiconductor plastics.

Tasks 1, 2 and 4 were necessary to confirm that results from the new test would correspond with results from the larger scale Parallel Panel test and to develop a meaningful classification scheme.

Samples of the following eight materials were tested:

1. Polypropylene
2. Fire retardant polypropylene
3. Takiron PVC™
4. Corzan™
5. Kynar HFP™
6. Clear PVC
7. Polycarbonate
8. Halar 901™

This appendix summarizes the results of the six tasks in this project. Complete information is available in the UL report *Report on the Research Investigation of the Combustibility of Plastics Used for Semiconductor Tools*.

**NOTE:** The units presented here are the units used in the UL report. For appropriate conversion factors, refer to PRC.18.2.

## CHARACTERIZING THE PARALLEL PANEL TEST IGNITION SOURCE

FM Test Standard 4910 describes the Parallel Panel test apparatus, which consists of metal frames for holding two 2-ft by 8-ft vertical panels 1 ft apart. A 1-ft by 2-ft sand burner using propane fuel generates a 60 kW ignition source between the panels.

Both heat flux and smoke release from the sand burner were measured with noncombustible panels in the test frame. Heat flux data were used to select the radiant heat flux for exposing the plastics samples in Task 2. Smoke release data were used to compensate for differences in smoke generation between the Parallel Panel and ASTM E1354 cone calorimeter tests.

## CONDUCTING PARALLEL PANEL TESTS ON THE SAMPLES

Three samples of each type of plastic were tested. Each test measured oxygen concentration, exhaust gas temperature, exhaust gas velocity and smoke obscuration. Flame propagation was noted for each test.

The heat release rate was calculated from these measurements by means of the oxygen consumption technique using the following equation:

$$\dot{q} = k_p \times \frac{\dot{V}(0.2095 - x)}{T(1.105 - 1.5x)}$$

Where:

$\dot{q}$  = Heat release rate (kW)

$k_p$  = Constant (kJ × K/m<sup>3</sup>)

$\dot{V}$  = Volumetric flow rate (m<sup>3</sup>/s)

$T$  = Exhaust gas temperature (K)

$x$  = Instantaneous mole fraction of oxygen

The value of the constant  $k_p$  includes factors for the heat release per kg of oxygen consumed, the ratio of the molecular weight of oxygen to air, the density of air at ambient temperature and pressure, the ambient temperature, and the calibration constant for the heat release calorimeter.

The smoke release rate was calculated from the following equation:

$$\dot{s} = \frac{\dot{V}}{\ell} \times \ln \left( \frac{I_0}{I} \right)$$

Where:

$\dot{s}$  = Smoke release rate (m<sup>2</sup>/s)

$\dot{V}$  = Volumetric flow rate (m<sup>3</sup>/s)

$\ell$  = Path length (m)

$I_0$  = Reference light beam signal (V)

$I$  = Instantaneous light beam signal (V)

The total smoke released was calculated as a time integral using the trapezoidal method. The specific extinction area is then the total smoke released divided by the sample mass loss:

$$\sigma = \frac{\int_0^{t_f} \dot{s} dt}{\Delta m}$$

Where:

$\dot{s}$  = Rate of smoke release (m<sup>2</sup>/s)

$\sigma$  = Specific extinction area (m<sup>2</sup>/g)

$\Delta m$  = Sample mass loss (g)

Table 1 shows the average of three trials for each type of plastic tested.

**TABLE 1**  
Average Results of Parallel Panel Test

| Plastic                      | Flame Propagation (ft) | Peak Heat Release Rate (kW) | Peak Smoke Release Rate (m <sup>2</sup> /s) | Total Smoke (m <sup>2</sup> ) | Sample Mass Loss (g) | Specific Ext. Area (m <sup>2</sup> /g) |
|------------------------------|------------------------|-----------------------------|---|-------------------------------|----------------------|--|
| Polypropylene                | >8                     | *                           | *   | *                             | *                    | *                                      |
| Fire retardant polypropylene | >8                     | *                           | *   | *                             | *                    | *                                      |
| Takiron PVC™                 | 3.8                    | 129                         | 17.3  | 6107                          | 7.88                 | 0.759                                  |
| Corzan™                      | 4.0                    | 122                         | 6.9   | 2719                          | 8.03                 | 0.339                                  |
| Kynar HFP™                   | 6.5                    | 219.3                       | 18.3  | 4914                          | 8.64                 | 0.566                                  |
| Clear PVC                    | 4.2                    | 192                         | 26.1  | 11,420                        | 8.94                 | 1.275                                  |
| Polycarbonate                | >8                     | *                           | *   | *                             | *                    | *                                      |
| Halar 901™                   | 3.0                    | 105.3                       | 13.1  | 5386                          | 6.06                 | 0.890                                  |

\* Tests terminated when flame height exceeded 8 ft.

## CONDUCTING THE ASTM E1354 CONE CALORIMETER TEST

This test measures oxygen concentration, exhaust gas temperature, pressure difference across an orifice plate, and smoke obscuration. The heat release rate was calculated from these measurements by means of the oxygen consumption technique using the following equation:

$$\dot{q} = k_c \times \sqrt{\frac{\Delta P}{T}} \times \frac{(0.2095 - x)}{(1.105 - 1.5x)}$$

Where:

$\dot{q}$  = Heat release rate (kW)

$k_c$  = Constant (  $\text{kJ}\sqrt{(\text{m} \times \text{K})} / \text{kg}$  )

$\Delta P$  = Pressure difference across orifice plate (N/m<sup>2</sup>)

T = Exhaust gas temperature (K)

x = Instantaneous mole fraction of oxygen

The value of  $k_c$  includes factors for the heat release per kg of oxygen consumed, the ratio of the molecular weight of oxygen to air, and the calibration constant for the cone calorimeter.

The total heat released was then calculated as a time integral using the trapezoidal method. Smoke release rate, total smoke released and specific extinction area were calculated the same way as in the parallel panel test.

Table 2 shows the average results of the cone calorimeter test in the horizontal orientation for selected properties of the tested samples. Several other properties were measured or calculated in these tests. The tests were also done in the vertical orientation.

**TABLE 2**  
**Average Results Of Cone Calorimeter Test**

| Plastic                      | Peak Heat Release Rate (kW) | Total Heat/ Unit Area (kW/m <sup>2</sup> ) | Peak Smoke Release Rate (m <sup>2</sup> /s) | Total Smoke (m <sup>2</sup> ) | Sample Mass Loss (g) | Specific Ext. Area (m <sup>2</sup> /g) |
|------------------------------|-----------------------------|--|---|-------------------------------|----------------------|--|
| Polypropylene                | 6.0                         | 179  | 0.11  | 29.3                          | 52.4                 | 0.557                                  |
| Fire retardant polypropylene | 5.4                         | 137  | 0.24  | 58.7                          | 51.6                 | 1.139                                  |
| Takiron PVC™                 | 1.6                         | 45   | 0.13  | 37.2                          | 67.3                 | 0.552                                  |
| Corzan™                      | 0.7                         | 24   | 0.06  | 6.9                           | 72.5                 | 0.094                                  |
| Kynar HFP™                   | 1.4                         | 70   | 0.13  | 46.6                          | 111.4                | 0.418                                  |
| Clear PVC                    | 1.7                         | 64   | 0.25  | 72.5                          | 75.5                 | 0.960                                  |
| Polycarbonate                | 2.5                         | 182  | 0.14  | 88.0                          | 95.8                 | 0.918                                  |
| Halar 901™                   | 0.3                         | 9  | 0.26  | 90.8                          | 83.5                 | 1.088                                  |

## CORRELATING PARALLEL PANEL AND CONE CALORIMETER RESULTS

The data collected in the parallel panel and cone calorimeter tests were used to determine the Thermal Response Parameter (TRP), Fire Propagation Index (FPI) and Smoke Damage Index (SDI) as specified in the FM 4910 test. The TRP was determined from the following equation:

$$TRP = \sqrt{\frac{4}{\pi}} \frac{1}{m}$$

This equation is derived from equations for flame height and flame propagation rate, and it is arranged to use measured and calculated data. (See the UL report for details.) The variable  $m$  is the slope of the line of least square fit in a plot of  $1/t_{ig}^{1/2}$  vs radiant heat flux. The tests measured the time to ignition,  $t_{ig}$ . The radiant heat flux was calculated from test measurements.

The  $FPI$  is then calculated as follows:

$$FPI = k \frac{(0.42\dot{Q}'' )^{1/3}}{TRP}$$

Where:

$k$  = Constant (1200 for calorimeter horizontal orientation, 1000 for parallel panel)

$\dot{Q}''$  = Peak heat release rate per unit sample area (kW/m<sup>2</sup>)

$TRP$  = Thermal response parameter (kW × s<sup>1/2</sup>/m<sup>2</sup>)

Finally, the  $SDI$  is:

$$SDI = FPI \frac{\sigma}{8500}$$

Where:

$\sigma$  = Specific extinction area (m<sup>2</sup>/kg)

Table 3 compares the FPI and SDI calculated from the parallel panel and cone calorimeter tests. The table shows that FPI and SDI values obtained in the cone calorimeter correspond well with those obtained in the parallel panel test.

**TABLE 3**  
**Comparison of Parallel Panel and Cone Calorimeter Tests**

| Plastic                      | Peak FPI<br>Parallel Panel | Peak FPI Cone Calorimeter<br>(horizontal) | Peak SDI<br>Parallel Panel | Peak SDI<br>Cone Calorimeter<br>(horizontal) |
|------------------------------|----------------------------|---|----------------------------|--|
| Polypropylene                | *                          | 20.5                                      | *                          | 1.34   |
| Fire retardant polypropylene | *                          | 21.5                                      | *                          | 2.88   |
| Takiron PVC™                 | 4.5                        | 5.0                                       | 0.39                       | 0.32   |
| Corzan™                      | 1.0                        | 0.5                                       | 0.04                       | 0.01   |
| Kynar HFP™                   | 8.5                        | 8.0                                       | 0.57                       | 0.39   |
| Clear PVC                    | 13.5                       | 14.0                                      | 2.00                       | 1.58   |
| Polycarbonate                | *                          | 9.0                                       | *                          | 0.97   |
| Halar 901™                   | 2.0                        | 1.0                                       | 0.22                       | 0.13   |

\* Tests terminated when flame height exceeded 8 ft.

**TABLE 4**  
**UL 2360 Prescriptive Classification Scheme**

| Test           | Property                   | Acceptance Criteria |                         |                          |
|----------------|----------------------------|---------------------|-------------------------|--------------------------|
|                |                            | Class 1             | Class 2                 | Class 3                  |
| ASTM E 1354    | FPI                        | < 6                 | Parallel Panel required | Parallel Panel required  |
|                | SDI                        | 0.4 or less         | 0.4 or less             | < 1                      |
| Parallel Panel | Propagation (ft)           | N/A                 | < 8                     | < 8 for the first 10 min |
|                | Pooling of melted material | N/A                 | No                      | No                       |

## DEVELOPING A CLASSIFICATION SCHEME

Two classification schemes have been developed, one a prescriptive scheme and one performance based. The prescriptive classification scheme is shown in Table 4.

Properties to be listed will include the following:

- Ignition Properties
- Critical Flux
- Thermal Response Parameter
- Combustibility Properties
- Mass Loss
- Heat Release
- Smoke Release
- Effective Heat of Combustion
- Specific Extinction Area

## DEVELOPING THE UL STANDARD

The standard *UL 2360 – Standard Test Method For Determining The Combustibility Characteristics Of Plastics Used In Semiconductor Tool Construction* has been developed and processed by the UL Standards Department. A scope of this document is available from the UL website at <http://www.ul.com/global/documents/offerings/industries/buildingmaterials/industrialcontrolpanels/literature/UL2360generalinfo.pdf>



## CONCLUSIONS

UL 2360 is a simple, reproducible test for the combustion properties of plastics. It was developed from test information on plastics used in making wet benches and other tools used in semiconductor industry cleanrooms. However, this test might also be applied to plastics used in other semiconductor applications, like mini environment partitions, wafer boats and portions of otherwise noncombustible equipment.

The one area where this test is not applicable is for testing of plastic and plastic lined fume exhaust duct. The conditions under which plastic duct is used are more severe than represented by the UL 2360 test. Test plastic and plastic lined ducts using the FM 4922 test. This test uses high velocity air movements within the duct to simulate real life conditions.